JOURNAL OF Petroleum Technology

FALL MEETING ISSUE SEPTEMBER, 1953

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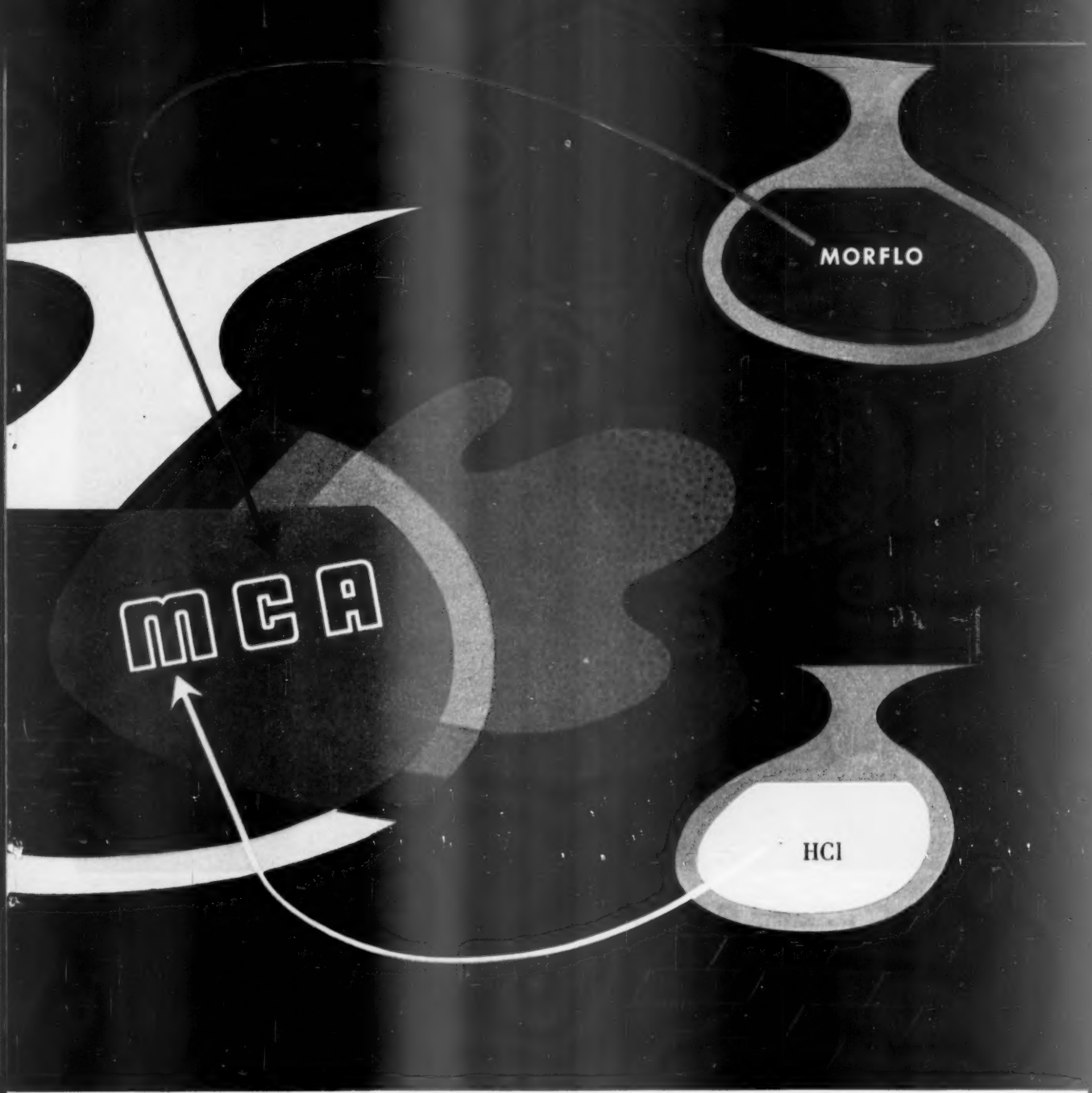

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Official Publication of the

PETROLEUM BRANCH
American Institute of Mining and Metallurgical Engineers, Inc.

800 Fidelity Union Bldg.
Dallas, Texas

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PETROLEUM RESERVOIR ENGINEERING

JOURNAL OF
Petroleum Technology

Fall Meeting Issue

Vol. V SEPTEMBER, 1953 No. 9

CONTENTS

Editorial Features — Section 1

A Review of the Chemical Treatment of Wells, By Paul E. Fitzgerald 11
Two Decades of Gun Perforating, By Reginald L. Robinson and Blake M. Caldwell 14
Twenty Years of Oil Well Cementing, By William D. Owsley 17
A Summary of Progress in the Drilling Industry, By Jack H. Abernathy 21
Directional Drilling Today, By Gordon Jackson 27
Two Decades of Electrical Logging, By H. G. Doll 33
Petroleum Production Equipment — Twenty Years of Development, By Carl E. Reistle, Jr. 45
Some Features of Growth in Fluid Injection Techniques, By William L. Horner and A. E. Sweeney, Jr. 51
Two Decades of Oil Reservoir Engineering, By Lloyd E. Elkins and S. J. Pirson 59
Gas Technology — Its Growth and Development, By Ralph E. Davis 67
Twenty Years of Growth in the Natural Gas Industry, By John M. Hanley 71
Twenty Years of Advancements in Geophysical Techniques, by Herbert Hoover, Jr. 77
Development of Techniques in Reserve Estimation, By Donald L. Katz 81

Fall Meeting

Dallas — Fall Meeting Site 85
Fall Meeting Officers 86
Fall Meeting Program 87
Technology Committee Members 89
Pacific Petroleum Chapter Fall Meeting 90
Abstracts of Fall Meeting Papers 91

Petroleum Transactions

Equilibrium Vaporization Ratios for Nitrogen, Methane, Carbon Dioxide, Ethane, and Hydrogen Sulfide in a Natural Gas-Condensate System, By R. H. Jacoby and M. J. Rzasa 225
Performance Predictions Incorporating Gravity Drainage and Gas Cap Pressure Maintenance — LL-370 Area, Bolivar Coastal Field, By D. R. McCord 231

Institute Affairs — Section 2

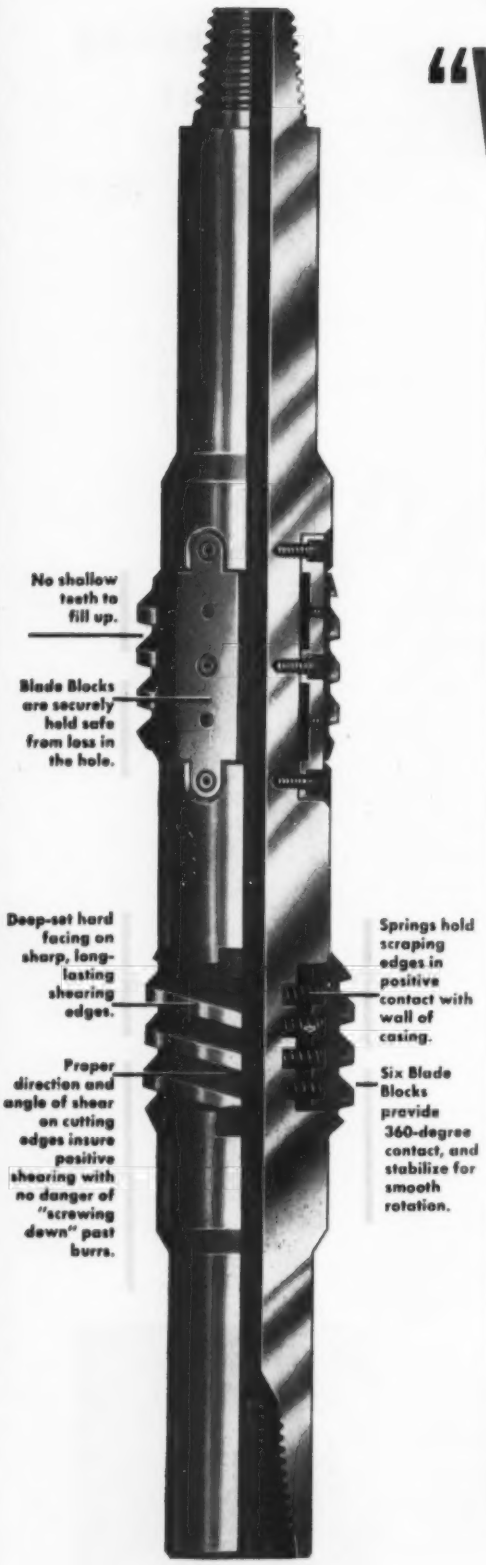
Professional Cards 2
Employment Notices 4
Petroleum Branch Membership 5
Personals 6
Schedule of Local Section Meetings 7
Advertisers' Index 8

This Month's Cover

Here and there in the oil patches of the world may be found an old, weather-worn bull wheel, long since discarded and put out of use. The scene becomes a symbol of outmoded techniques and abandoned methods. The petroleum industry has come a long way since the heyday of the bull wheel reposing on the cover. Leading the way has been the petroleum engineer, never satisfied with present methods, always seeking after more knowledge of the forces responsible for the occurence of petroleum. Most of today's knowledge has been gathered over the past 20 years. Hence, to that period in time this issue is devoted. Sixteen of the engineering profession's top men were asked to comment on advancements made in various fields of the industry. Their comments are set forth on the following pages.

—Photo by Humble Oil & Refining Co.

How is the
"Working Surface"


No shallow teeth to fill up.
Blade Blocks are securely held safe from loss in the hole.
Deep-set hard facing on sharp, long-lasting shearing edges.
Springs hold scraping edges in positive contact with wall of casing.
Proper direction and angle of shear on cutting edges insure positive shearing with no danger of "screwing down" past burrs.
Six Blade Blocks provide 360-degree contact, and stabilize for smooth rotation.

Baker Model "C"
ROTO-VERT Casing Scraper
Product No. 620-C

Unless the inside of your casing—the vital "working surface"—is clean and smooth, there is always a possibility of trouble in future operations. Burrs from gun-shot perforations, hardened cement or mud, and even mill scale are all dangerous when the time comes to run testers or swabs, or to set cement retainers or packers of any description.

The Baker Model "C" ROTO-VERT Casing Scraper removes all obstructions from the inside of the casing, leaving it clean and smooth. Burrs or imbedded bullets are sheared away; cement, mud and scale are scraped away, so that any down-hole work can be safely done at once, or during the years to come.

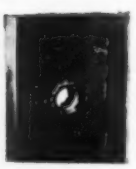
SCRAPE WHILE DRILLING OUT

The ideal time to use the ROTO-VERT Casing Scraper is during the drilling out of cement, at which time it is run as a "follow-up" behind the bit. Thus in a single run you can also remove all hardened cement, mud, burrs and scale which might *later* damage swabs or testers, and cause packers or retainers to set prematurely—or never set at all.

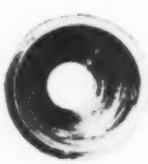
EASY TO RUN—LOW-COST RENTAL

The Baker ROTO-VERT Casing Scraper is simple to run, and will effectively clean the inside of the casing when either reciprocated or rotated.

No service man is required, and the low rental cost is paid for many times over by freedom from future damage to bailers, swab rubbers and packers, as well as by the elimination of future delays and re-running expense.



SEE HOW THIS BURR... ripped this packing element,



and how ROTO-VERT could have prevented the damage by shearing away the burr.

# of your casing?

WHY **THE ROTO-VERT IS SAFE AND SIMPLE TO USE AND COSTS LITTLE TO RUN**

This helix-blade-type scraper can be either "spudded" (reciprocated vertically) or rotated for the removal of gun-perforation burrs, imbedded bullets, cement sheath or other obstructions from the inside of the casing.

The body is machined from bar stock, with two sets—a total of six—rugged Blade Blocks positioned for overlapping, 360-degree scraping coverage. The most outstanding feature of the Blade Blocks is the direction and angle of shear of the scraping edges. The slant of these scraping surfaces is in a direction OPPOSITE from that encountered on other helix-blade-type casing scrapers, and the shearing edge is set at a smaller angle from the horizontal. These features result in the fact that the ROTO-VERT will not "screw" down past burrs as it is being rotated. And when it comes to removing cement sheath or other casing coatings, you are assured of actually removing the material with the ROTO-VERT, instead of merely cutting threads in it.

REMOVING PERFORATION BURRS AND BULLETS

On rotary rigs best results are obtained by first running the ROTO-VERT Scraper *completely through* the perforated section WITHOUT ROTATION. This initial run will either shear or knock off the majority of imbedded or projecting bullets, and shear away most of the ragged perforation burrs. Then pull back the ROTO-VERT Scraper and rotate it through the perforated section. This second run permits the helix scraping edges to shear to their fullest extent, leaving perforation holes practically flush with the casing I.D., and the entire perforated section clean and restored to gauge.

When running the ROTO-VERT on tubing, or on a wire line (with suitable sinker bars and jars) it is merely run through the perforated section, then pulled back and run through again. If the ROTO-VERT runs through the perforated section smoothly (as indicated by checking the weight indicator) complete burr and bullet removal is a certainty.

REMOVING CEMENT SHEATH, HARDENED MUD OR SCALE

Recommended procedure is to install the ROTO-VERT just above the bit when drilling out cement, to remove the thin sheath of cement always left, even though a maximum gauge bit is being used. Hardened mud, cement, paraffin, or mill scale are completely removed in a single run.

On old wells (or when rotary equipment is not present) the ROTO-VERT, run on tubing, will successfully remove various casing coatings WITHOUT ROTATION. A spudding action usually quickly clears up any rough or stubborn "tight spots."

A modified ROTO-VERT can be furnished to operate with equal success when run on a wire line equipped with sinker bars and jars.

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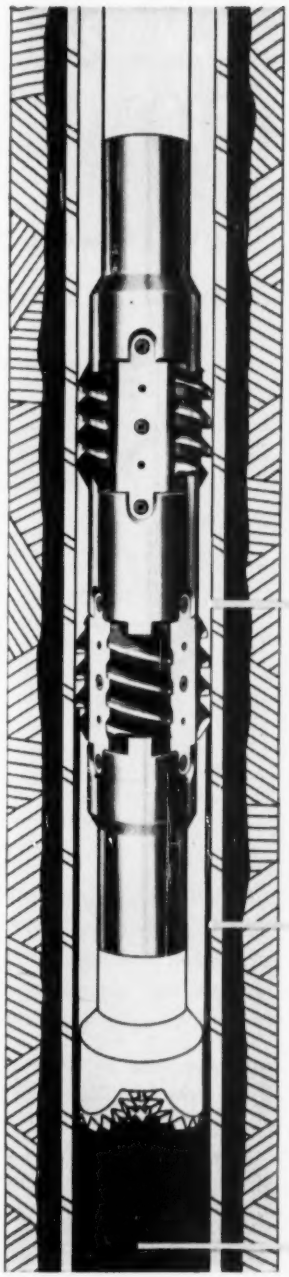


Even when a maximum gauge bit is used for drilling-out, a thin sheath of hardened cement remains to interfere with future operations. To visualize how ROTO-VERT removes this sheath, see left.

All cement, scale, burrs, etc., have been removed by the ROTO-VERT Scraper, and the vital "working surface" of casing is left clean and smooth.

This thin sheath of hardened cement always remains after the bit has passed.

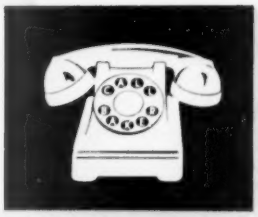
Cement to be drilled out.

Cross-section of casing showing gun-perforation burr, before scraping . . .

and after ROTO-VERT was run.

This brittle cement sheath prevents the slips of pack-off tools from gripping the casing.

. . . Here is cut section of the same casing showing how slips tried, unsuccessfully, to set against the cement sheath.



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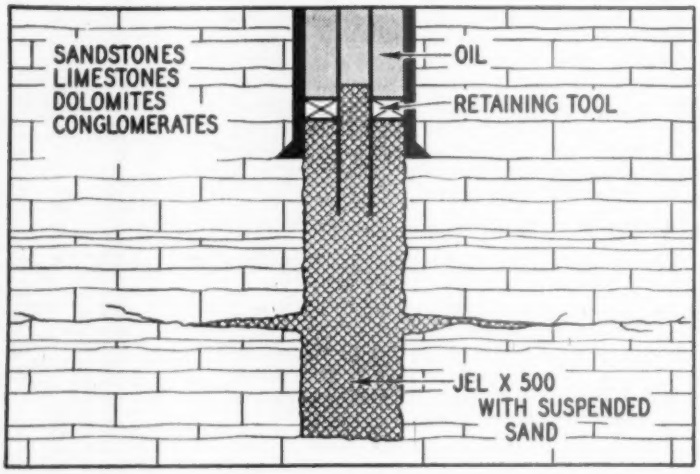
New Dowell Service Combines Advantages of Acidizing and Fracturing in Single Treatment



This well's initial production was 19 BOPD. While the well had not declined, it was not considered good for its location. After various other remedial methods had failed, a Dowell Stratafrac treatment increased oil production to 45 BOPD. Payout time was estimated at 36 days.

Stratafrac treatments using Jel X 500 have increased production from all types of oil bearing formations—limestone, dolomite, sandstone, chat and conglomerate. This service is designed to fracture and acidize the formation in a single operation.

Stratafrac treatments carry suspended sand into existing fractures as an abrading and propping agent. They are also designed to remove paraffin or other heavy hydrocarbons present in the fractures or formation.

Stratafrac treatments are engineered to save you money by holding rig time to a minimum. All materials arrive at the well ready-mixed. No jel-breaker solution is needed following Stratafrac treatments, as the material returns to the well bore as a thin, free-flowing liquid. The well can be returned to production immediately without costly shut-in time.

GET THE FACTS ON STRATAFRAC! Find out how Stratafrac has increased production in many fields. For a more detailed discussion on this new Dowell service, call your nearest Dowell station or write direct to Tulsa, Dept. N-15.

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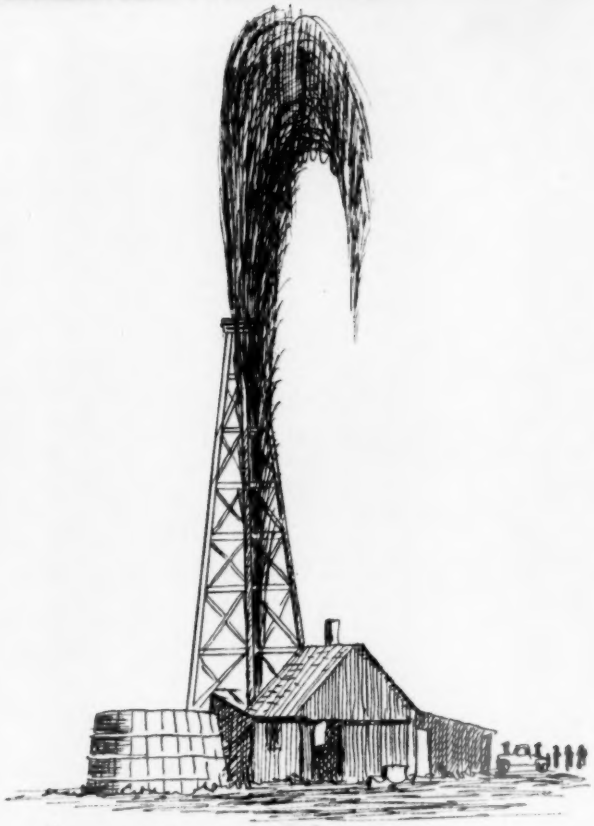
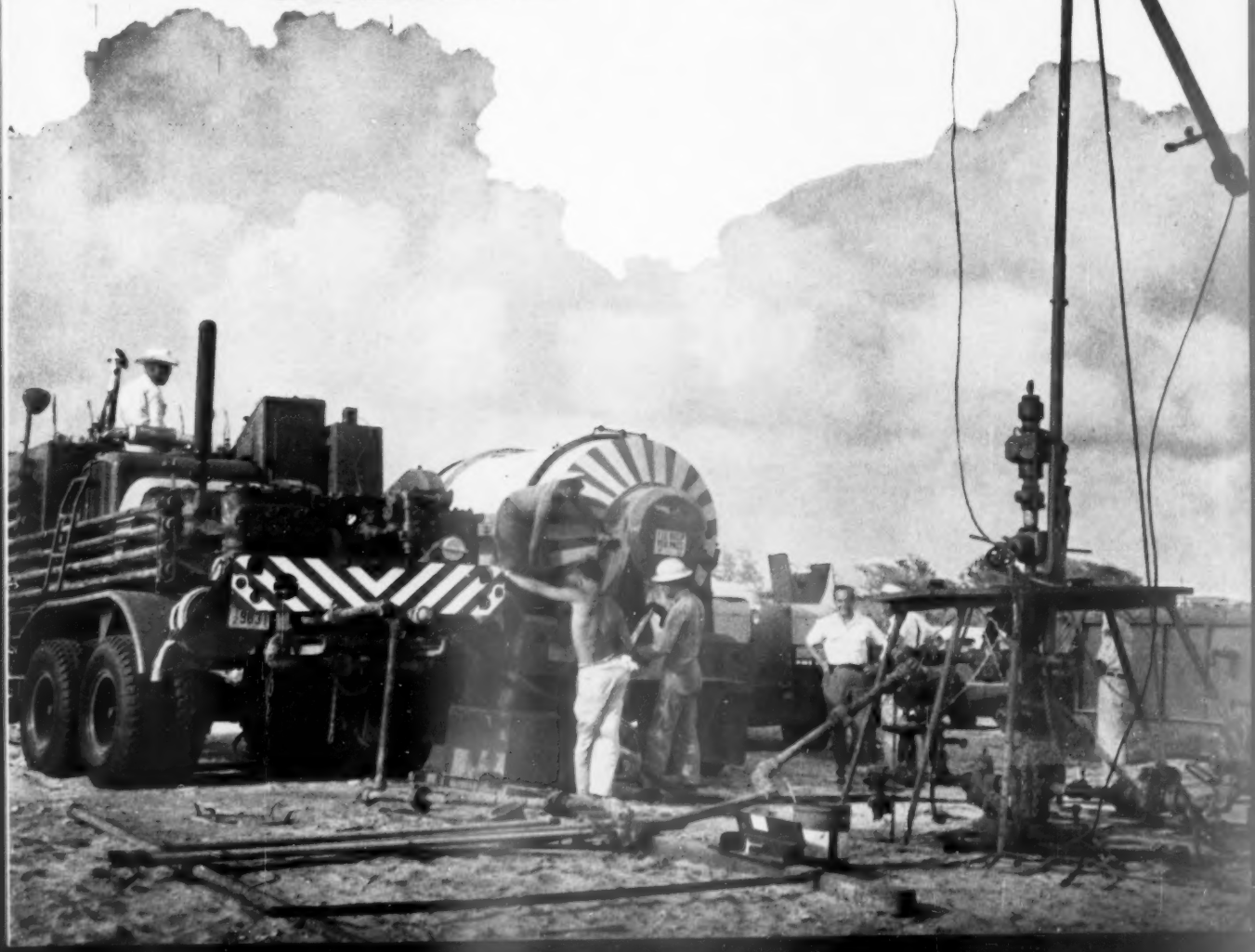
WELL COMPLETION





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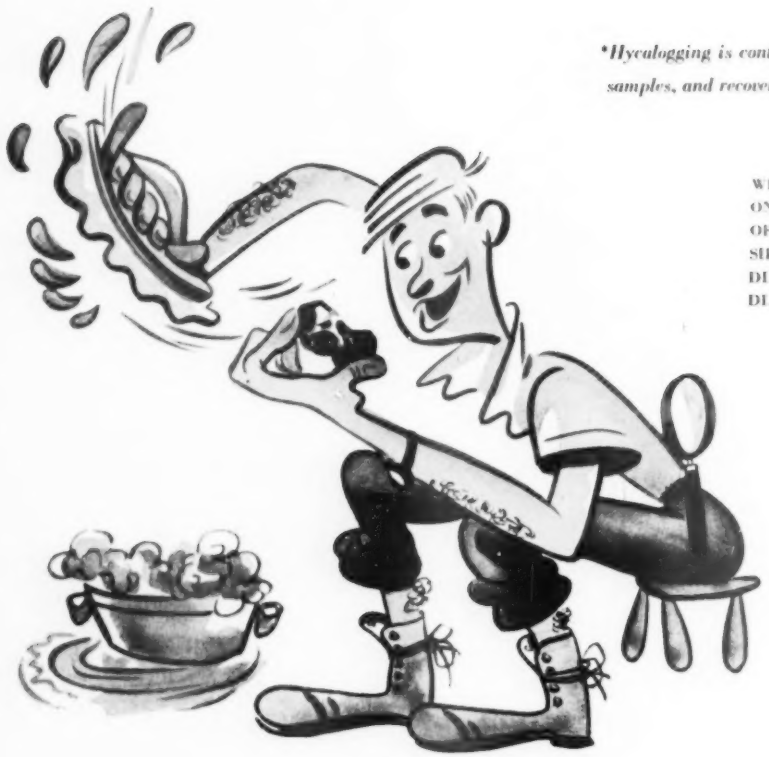
. . . For Hycaloggers, with the experience of logging over 800 wells, have solved this problem. Their researchers in the Hycalog laboratories have produced the answer—a special technique which cleans cuttings thoroughly without affecting their composition, permitting full evaluation even when drilling fluids contain oil.

May we show you how Hycalogging* gives you the whole story on formations, under any drilling conditions.

*Hycalogging is continuous hydro-carbon logging of cuttings, mud samples, and recovered cores.



WELL LOGGING
ON LOCATION CORE ANALYSIS
OFF LOCATION CORE ANALYSIS
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A Review of the Chemical Treatment of Wells

By

Paul E. Fitzgerald

Dowell Incorporated

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During the past 20 years the use of chemicals in wells has become a universally accepted procedure, a progressive force in the business of producing oil and gas. The magnitude of this activity is better understood when it is learned that in 1952, more than 65,000,000 gallons of various chemical mixtures were used in approximately 45,000 wells in the United States and Canada.

Perhaps a review of some of the events leading to the development of this phase of the oil industry will be interesting.

It was in 1895 that chemicals were first used in wells in an attempt to increase oil production. This early work was carried on by two men, Herman Frasch and John W. Van Dyke, both of the Solar Refining Company of Lima, Ohio.

In 1895, Frasch was chief chemist at Standard's Solar refinery in Lima, where he was developing his method for refining the sulfur-laden oil produced from the Trenton limestone. He was interested also in the erratic behavior of many of the wells that produced the oil being refined at Solar. He believed that the reason some of the wells gave up their store of oil freely and in great amounts while others did not was because of wide variations in the permeability of the limestone.

This quirk of nature was discussed often by Frasch and his friend, J. W. Van Dyke, general manager at Solar. To these men the solution to the problem was not difficult. They reasoned that if a suitable volume of muriatic or sulfuric acid was forced into the acid-soluble rocks surrounding the well bore, these "tight" wells should release their oil because some of the rock would be dissolved away in the acid.

The Corrosion Problem

Frasch and Van Dyke realized that the concentrated acid they planned to use in their "well treatments" would corrode the steel equipment of the wells. Accordingly, Frasch discussed the corrosion problem with the Ohio Rubber Company of Cleveland. Mr. G. N. Talcott of this company, reported that it would be difficult to line pipe with rubber so that it would give satisfaction and suggested the use of a hose to introduce acid into the bottom of the well.

Their first chemical treatments are reported in the October 10, 1895, issue of the Oil City, Pennsylvania, Derrick. On March 21, of the following year the Derrick reported the method to be "beyond the experimental stage . . . production can be increased where all other methods fail."

References at end of paper.

It is interesting to note that both Frasch and Van Dyke applied for and obtained patents on the use of acid in wells, one patent teaching the use of hydrochloric acid and the other sulfuric acid. They assigned one-half of their patent rights to the other, thus providing a basis for the assumption that they were not certain which acid solution would provide the best results.

But interest in this revolutionary method declined and it was not long until little or no news of the Frasch-Van Dyke chemical treatment was to be heard. The reasons for the decline of interest in this new scientific approach to a troublesome production may have been obscured by the passing of the years but, no doubt, the physical nature of the rock, the chemical composition of the solvents and the treating techniques all combined to defeat these pioneers.

As the pioneering wildcatter moved westward, many new fields were discovered in Illinois, Oklahoma, Kansas, and Texas. The question of how to cause a permanent physical change in the reservoir rock so that the oil would be given up more freely continued to plague the minds of the increasing number of men who drilled for oil. There is no record to show, however, that the teachings of Herman Frasch were being given much serious consideration.

It was not until the booming twenties rolled around that

The Author

Early Acidizing truck capable of delivering 80 gals. per minute at 1,200 rpm. This unit was of little use on wells of more than 200 psi.

the records reveal another approach to the use of chemicals in wells. This time it was an attempt to remove "gyp" deposits from the tubing of oil wells. The leader in this work was the Gypsy Oil Company who made numerous "gyp" removal treatments. Other treatments were made by Eastern Gulf Oil Company in Kentucky, but there experiments, as well as those of Gypsy Oil, were discontinued by 1930 when no outstanding results were secured.

The discovery of oil in the limestones of central Michigan in 1927 by The Pure Oil Company brought into focus again the same problem that had aroused the curiosity of Frasch and Van Dyke — some of the wells were good producers, while others nearby were unprofitable or completely devoid of free oil.

Use of Hydrochloric Acid

Not far from these Michigan fields The Dow Chemical Company had their plants which utilized brine from wells located in the same area as the oil wells. One of the products produced by Dow in large volumes was hydrochloric acid. Perhaps it was the desire to find an additional use for hydrochloric acid or to find an effective and economical way of disposing of waste brines from the Dow plant, that caused some experimental chemical treatments to be made on several of the brine wells. These tests, begun in 1929, were made to increase the permeability of the Marshall sand. The work was successful to a considerable degree because reports show that one of the wells would take as much as 50,000 barrels of waste fluid per day. Another Marshall well was tested to see if it would produce more brine than before treatment. This test was also successful as the sand gave up 30 per cent more fluid than before treatment.

It was not until later in 1931, however, that a cooperative program was worked out by Pure and Dow to put inhibited acid into an oil well.

The first treatment was made on February 10, 1932, increasing the production of the well substantially. Other chemical applications were made on additional wells in short order with excellent results. By the end of the year, more than 300 wells had been treated and there was no doubt that the process had commercial possibilities.

The news about this chemical method of reviving wells spread rapidly and within a year or two acid was being used in wells wherever the oil was found in calcareous rocks. Well treating companies were formed by the score, some of which were successful and are still active today.

It was not long until it was learned that the pumps and transport equipment available for this work were unsuited. Much research and design engineering work on the part of the service companies has resulted in the highly mobile, powerful units currently in use in the oil fields today. The illustrations accompanying this article demonstrate the advances that have been made in equipment design. And the end is not in sight as the demand for pumps capable of handling larger volumes and very high pressures are holding the interest of engineers who design and build oil well servicing equipment.

Introduction of Addition Agents

The first acidizing treatments were made on wells producing oil from highly soluble limestones. However, an early appreciation of the variation in the characteristics of the reservoir stimulated research leading to the introduction of chemical addition agents and techniques that extended the use of the process to more complex formations. For example, surface tension reducing agents were used in Ohio well treatments in December 1932, and by the middle of 1933 were in general usage. Fluoride compounds were added to the acid in 1933 to speed up the reaction of the solvent on dolomites and siliceous rocks. Then came solvents that dissolved the silicates in the oil bearing formations and drilling fluids. These solutions also contained surfactants, demulsifying compounds and suitable corrosion inhibitors. With the production of oil from very deep, high-pressure, high-temperature reservoirs, the research chemist made available corrosion inhibitors and other addition agents that perform satisfactorily regardless of pressure and temperature. Corrosion inhibitors are being used today where at temperatures of 350°F the metal loss is only .03 pounds per square foot per day.

It was early in the history of the well treating industry that engineers realized the need for techniques to control

Present day unit will deliver 8.5 bbl per minute at 1,500 psi or 70 gals. per minute at 7,500 psi. This pump will operate at pressures up to 10,000 psi.

the introduction of the chemicals into those pay zones in which the chemicals would produce optimum results. The early attempts at selective acidizing were more or less crude by the development of equipment utilizing down-the-hole electrodes and surface recording instruments took much of the guess work out of the selective acidizing technique. Today the Electric Pilot[1,2] method is used extensively for locating and evaluating zones of permeability and for controlling the entry of the chemicals into those zones selected for chemical treatment.

The increasing interest of the petroleum engineer in maximum recovery of petroleum has also stimulated the management of the service companies to expand their research programs and enter areas of study heretofore reserved for those interested in reservoir engineering and petroleum geology. The crossing of this threshold is already producing improvements in materials, introduction of new approaches to solution of old problems and many additional techniques, tools and chemicals.

As an example of the results secured from the enlarged research horizon there are in use now chemicals that minimize the swelling effects of silicates[3] present in many oil producing formations and acid gels that form small channels[4] in the rock and thus extend the effect of the solvent on the rock.

Radioactive Compounds

Extensive studies on rock thin sections and well treating results are also producing data of real value in the development of materials designed to produce optimum results from the chemical treatment. Two decades ago, when the acidizing process first became commercial, a relatively few chemicals were relied upon, but today the service company engineer has available to him several hundred compounds which can be used in preparing a treating mixture for a specific formation.

The release of radioactive compounds by the Atomic Energy Commission has opened up an entirely new avenue of study. The development of Geiger counters and other electronic equipment that will withstand the pressure and temperatures encountered in wells is leading to even greater efficiencies and economies in the chemical servicing of wells. The use of these new tools in conjunction with radioactive chemicals is providing the petroleum engineer with additional data that are sure to help him secure that last elusive drop of oil from the reservoir.

Within the last few years interest in a different type of well treating technique has become intense. Everywhere oil and gas are produced there is heard discussion about the various "fracturing" methods of improving wells. Strangely enough, discussion of the possibility of this method appeared in print more than 18 years ago.[5,6] It remained, however, for the cooperative research of an oil company[7] and a service organization to develop this old idea into one of the most dramatic techniques for improving wells.

Highly Viscous Fluids

The use of highly viscous fluids capable of carrying as much as seven pounds of graded sand per gallon, is finding wide application on oil producing formations everywhere, and especially in sands not ordinarily susceptible to treatment using conventional acidizing techniques. Some appreciation of the interest in this "fracturing" method can be gained from the fact that in the four and one-half years since the process was first considered commercial, approximately 30,000 treatments have been made.

From the standpoint of economics, the various well treating methods have proven themselves to be of real value to the oil operator. In countless cases the well investment has been saved because a "dry hole" has been converted into a profitable producer. In some instances marginal properties have been turned into valuable ones simply by the application of one or more of the various chemical treatments now readily available. Evidence of the revived interest in old properties is to be seen on every hand. Many of these are already taking on new life and are giving up economically significant volumes of oil.

It might even be said that some of the chemical methods can be called exploration tools, as they have been used to recover oil that might never have been available except for their wise application.

Future Developments

A prominent engineer said recently, "The last half of the twentieth century will be underscored by research in secondary recovery." This being the case, the organizations that serve the petroleum industry can be counted upon to do their part. Their research and development departments are conducting extensive programs that are sure to produce better materials, improved equipment and more highly specialized treating techniques that should prove themselves of real value in helping the engineer secure the maximum recovery of oil from the rocks.

The wide-spread acceptance of the acidizing process has been due, in part, to the research programs carried on by the service companies, but an even greater amount of the credit for the development of the method and the present status of the business belongs to the oil industry, which has always been characterized by men willing to try new ideas. This friendly, cooperative relationship between men interested in the proper use and conservation of our petroleum resources is sure to result in methods and processes of oil production vastly superior and more economical than those presently being used.

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Two Decades of Gun Perforating

By

Reginald L. Robinson and **Blake M. Caldwell**

Welex Jet Services, Inc.

Members AIME

Several thousand years ago, Ling, the Chinese driller, was drilling for salt water, if you can imagine that, to be dehydrated and used for household purposes. His problem of casing his hole was not too different from ours. He used bamboo pipe and we use steel. We don't know whether he set through or completed "barefoot," but he did have a well completion problem, just as we do today.

Well completion techniques have been greatly influenced by perforating. This influence has been so great that our reserves have been scaled upward many times. Perforating has made possible recovery of oil and gas in some fields that would have otherwise been impossible. It has even opened up old fields to greater production than the initial flush production.

Before the development of in-place perforating, the practice of shop perforating pipe with a drill, milling slots, or cutting slots with an acetylene torch was common and to some extent is still practiced today. This method did serve its purpose but was limited in its application.

In-place perforating was first accomplished by mechanical perforators that were run on tubing or drill pipe. Since this was not a positive method of perforating, some operators were led to believe that their wells were barren, or at best, small producers, whereas if the casing had been perforated with today's equipment they would possibly have been good producers.

Mechanical perforators, other than being uncertain in their action, had a tendency to deform the casing and, in some instances, to such an extent that the casing would collapse or part at the perforated section. As a result, the practice of mechanical perforating was held to a minimum and most wells were produced from an open hole.

Development of Bullet Perforating

Shortly after the Drake well was brought in in Pennsylvania, a man with an idea for using explosives finally persuaded an early operator, whose well was a poor producer when his surrounding neighbors had good producers, to let him detonate several sticks of dynamite in his well. Of course this was in an open hole section and was not perforating, but it was the first use of explosives in an oil well. It was very successful and explosives have been used in oil wells since that time.

Early in the 1930's some enterprising men developed an advanced tool for the oil industry — this was the bullet perforator. This device used explosives to propel a projectile through the casing for perforations and was outstandingly successful over all previous methods.

With the advent of the bullet perforator, the practice of perforating casing became commonplace and the perforating industry finally came of age. The early guns, firing bullets, were usually effective. They brought in many new wells and also gave a new lease on life to hundreds of old wells which might otherwise have been abandoned.

After the introduction of the bullet perforator, it reigned supreme for some 15 years, then the inevitable occurred as it always does. Someone had an idea, "Why not take the Bazooka of World War II fame and shoot it into the casing?" It would punch holes through the toughest tanks, so it would surely penetrate casing and perhaps go back into the formation. The shaped charge, borrowed from the Bazooka, had the advantage of the research facilities of the military brain power behind it. This wealth of technical knowledge enabled the jet to be quickly adapted to perforating without the first faltering steps and later development period of its predecessor.

The Shaped Charge

The shaped charge, commonly referred to as a jet charge, or perforator, came through its development stage in a very short time and revolutionized thinking on well completion and perforating techniques upon its release to the oil industry. This new development in perforating offered the advantage of positive perforations and greatly improved penetration. These advantages quickly placed it in the limelight and it was soon accepted throughout the world wherever perforating was practiced.

Perforating was first devised as a means of making holes

The Authors

B. M. Caldwell

R. L. Robinson

in casing for the entrance of oil and gas. From that original idea, which has been greatly expanded, the practice of perforating has had many demands placed upon it. It still must produce a hole in casing, but in addition, occasionally must shoot through as many as three strings of casing separated by cement, sometimes through a cement sheath on the outside of the casing, through a mud sheath deposited on the well walls while drilling, through a contaminated section of formation, then back into the clean formation to produce good formation flow characteristics. This is but one of the numerous requests that perforating companies are daily receiving.

The tremendous increase in technological studies have revealed that perforating a well is an individual problem and must be treated as such. No generalized specification can be continually applied to all wells with best possible results. To meet these problems, many variations of perforating equipment have been developed.

Deep Penetration

Instances continually occur where deep penetration is imperative. Perforating companies have a tool for this. Again it may be that perforations are needed near an oil-gas or oil-water contact zone and the cement must not be cracked. This can be accomplished with equipment available today. Then again it may be desirable to fracture the cement behind the casing — this, also, is possible.

If an operator has a gas well or an oil well with exceptionally high bottom hole pressures, it may be to his advantage to perforate with small holes, but yet permit the desired flow. There is an answer for this problem.

Another question arose where it was desirable to gravel-pack the formation. "Could we perforate casing with holes whose diameter was no greater than ¼-inch?" Yes, that problem was solved and successful gravel packs have been made behind these small perforations.

Now, again to penetration. What about it? Laboratory tests have shown that penetration to a certain depth is essential. The depth for any particular formation is not known but a pilot model set-up did show that a direct relation exists between penetration and well bore.

What if one is not interested in penetration as much as he is in holes in the pipe? That instance often arises in squeeze cementing. Special applications sometime occur where a specific hole pattern is essential. The common perforating pattern is a spiral of single shots in a given horizontal plane. In addition to this single shot spiral pattern, there is a charge that shoots from both ends, giving two shots in a common horizontal plane. Squeeze cementing studies found that cement squeezed through perforations would not meet if the arc of travel from the perforations was too great, so why not develop a means of shooting four holes simultaneously in a common horizontal plane spaced on 45° increments? This tool was developed and is being enthusiastically received by the industry. Why does it make squeeze cementing more positive? Because the cement going through perforations does not have to travel, on the average, over 22½° from the hole in the casing from which it entered until it contacts cement from another hole. This ensures a solid cement sheath and places more cement behind the casing with less pump pressure. This decrease in pump pressure lessens the possibility of permanent formation damage and relieves undue strain on tubing and casing.

Occasionally a distraught voice on the other end of the telephone line asks, "My drill pipe is stuck, or my drill pipe is cemented in the hole. Can you perforate drill pipe and go back in the formation far enough to get a test?" The answer is usually yes. Perforating drill pipe for production has been done many times.

Sometimes tubing must be perforated. It can be done if the tubing I.D. is large enough to permit entry of the gun.

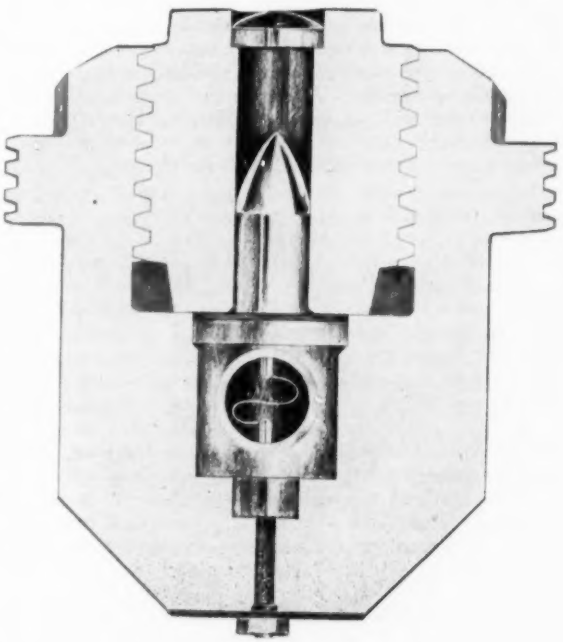
Another innovation that has recently been released to the industry is the permanent type well completion. This embodies a perforating gun small enough to perforate casing when it is shot below the tubing. Perhaps its greatest advantages are the savings in rig time, since the tubing and well head are made up before perforating, and having oil on the formation when it is perforated. If the well tends to blow, it can easily be controlled with its permanent well head system. Then, too, the mud has been displaced and oil is usually on the formation, reducing mud contamination problems.

If it is desired to perforate and test or produce immediately after perforating, such a service is available. The equipment is run on tubing or drill pipe and is available in either jets or bullets.

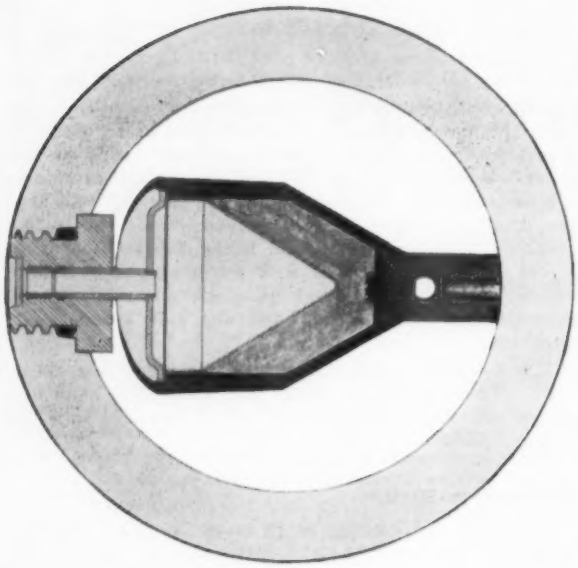
Perforating Guns

A general classification of all types of guns or carriers being run into wells falls into the classification of solid steel carriers from which bullets are usually shot and sometimes jets, the hollow steel tube from which jets for casing perforating is usually done and a metal framework containing jet charges. Each type carrier has its applications and its advantages. The perforating companies are compelled by the type of perforating desired to use a suitable carrier to run in the well.

What size of perforating equipment is available? The tubing gun used in the permanent type well completion is the smallest. It will run through 2-inch tubing so it must



Cross Section of Bullet Perforator



Cross Section of Jet Perforator

have an O.D. of not more than 1¾ inches. Choice of a number of sizes is available, but selection of size should be made in conjunction with the perforating company, since they are familiar with the application of the various types available to different well conditions.

How is the equipment fired? Again a wide choice is available. Jet charges are either simultaneously or semi-simultaneously fired, whereas bullets can be selectively fired (each shot), semi-selectively fired, simultaneously fired, or semi-simultaneously fired. What are the methods of firing? The most common is by an electric current. It can be done by hydrostatic pressure of the wells or by some derivation such as a go-devil detonating an explosive charge.

The younger brother of casing perforating is open hole shooting. Open hole shooting has been practiced for years, but it was not until the advent of the jet charge that positive control of open hole shooting occurred. This type shooting usually embodies the use of individually self-contained charges secured to a rack, lowered into the well and shot. The complete unit below the cable head or connection is considered expendible and usually left in the hole. How does this type of shooting relate to casing perforating? Some operators prefer this type of charge to be shot inside their casing. Since these charges usually have more energy to expend, they are difficult to contain in hollow steel tubes, therefore, the extraneous energy is released directly into the casing or well bore without benefit of an energy or pressure absorber. This shooting, being different from conventional perforating, can cause severe casing damage under some conditions. To offset this, these charges usually give greater penetration and larger holes than any other type of shot. This method of shooting has been very effective for water input wells in water flood projects. Again, shooting this type of charge should be discussed with the service company representative.

Open hole shooting on its own is now widely accepted where wells are completed with the casing set on top. It is a very powerful tool and can open up formations that heretofore were inaccessible.

The use of open hole and conventional casing perforating devices have been particularly useful in acidizing operations. These shots bare the formation to the treatment fluid. They decrease the formation breakdown pressure since the formation has a fracture made from shooting at exactly the desired spot.

Another use of perforating under study is in conjunction with hydraulic formation fracturing. A method is used where the perforating gun is lowered into position, then the hydraulic fracturing fluid is pumped under pressure around the perforating charge so that immediately after perforating the fracturing fluid is forced into the fracture created by perforating. It is felt that this will give a positive control over the fracture point in the formation and lower the pump pressure necessary for continued formation breakdown.

Cutters and Hole Openers

New tools are coming from the perforating companies that are cousins to perforating and are, therefore, mentioned here. Jet casing cutters are available that almost instantaneously cut casing at any desired point. They have been perfected to such an extent that they can cut one string of casing without cutting another concentric surrounding string. This tool saves valuable rig time on casing cutting jobs.

Another tool now in the field test stage is a jet casing "hole opener." A series of charges cuts the pipe into small fragments which fall to the bottom of the hole where they are left or fished out with a magnetic fishing tool or some other recovery device. The opened section of pipe then enables an operator to set a whip stock for side tracking operations or opens the formation up for any type treatment desired.

When explosives were first used, skeptical arms manufacturers had little to offer in the way of heat resistant powder for use in wells, but the temperature problem then was not acute since the wells were not too deep. The last 20 years have seen holes drilled deeper than 20,000 ft. What are the chances of perforating a well this deep? Chances are good. Temperature resistant explosives have been developed that will withstand any likely temperatures encountered. Wells have been successfully perforated with jets at approximately 400°F. The operating temperatures of bullet perforators have been increased to the range of 300°F to 325°F.

Right along with the temperature problem comes the hydrostatic pressure problem. So, along with the drilling industry's ability to drill deeper, perforating equipment has been developed that will go deeper and withstand the higher pressures and temperatures. Recently a perforating company was called to perforate a well. When the order was taken the question was asked, "What weight mud is in the hole?" The answer was, "Approximately 19 lbs. per gal." The perforating company then asked, "Can you condition your mud and make it a little lighter?" "Yes," was the answer. "Come on and it will be ready when you get here." It was. It just weighed 17½ lbs per gal. Pressures over 12,000 psi have been encountered and successfully perforated. Perforating depths near 17,000 ft are being perforated more frequently as drilling operations go deeper.

Yes, perforating techniques have changed in the last 20 years. Slowly at first but with gaining momentum. The last five years have seen many changes and more can be expected with increasing rapidity. Demands on the perforating industry for improved and new services will be made. The perforating industry, spurred on by competition, will fulfill these demands.

Twenty Years Of Oil Well Cementing

By

William D. Owsley

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Member AIME

Twenty years ago neither life nor oil well cementing seemed to be any less complex than they are today. Yet, looking across the years from the East Texas boom to present day oil field activities, we see many changes, many advancements, much progress.

In the Conroe Field in 1932 and 1933, some 250 sacks of cement behind a long string of casing frequently required all the pressure of which the then used cementing pumps were capable, this being about 3,000 psi. Later knowledge showed that this difficulty was principally due to the drilling muds then in use. With today's techniques, cementing long strings at Conroe would not be attended by problems considered at all difficult.

Squeeze Cementing

Squeeze cementing began about 1933 in the Texas Gulf Coast country. The early squeeze jobs were certainly more of a shot in the dark than the application of any scientific knowledge. Neverthless, they worked. Squeeze operations have been the direct cause of much progress in all oil well cementing procedures. The early jobs were done without the benefit of bottom hole packers, knowledge of cement dehydration, retarded setting cements and other things which today we consider commonplace. Gradually squeeze cementing procedures became routine, everyday operations following the development of permanently set drillable squeeze packers, hydraulically actuated removable packers, cementing equipment capable of in excess of 10,000 psi operating pressure, chemically retarded cements and various cement additives.

About 1932 methods for shutting off bottom water, including plugging back with cement, probably were no more than 15 per cent to 20 per cent effective. Contrast this with 1953 where squeeze cementing jobs are, in all probability, more than 70 per cent effective.

Remember back when the words "flash set of cement" were commonly used? Today, we hear very little of such occurrences since the mechanics and chemistry of cement dehydration and cement retardation are so much better understood. We did not then know that a simple collar leak could, and frequently did, allow enough water to escape from a cement slurry to render the mass solid at that point and incapable of being pumped further through the pipe.

Casing cementing procedures have undergone great changes. Even in the very early days of casing cementing the use of bottom plugs was taught. These plugs offered some difficulty in use; in fact, they were more than a bit of a nuisance, and since jobs seemed to work as well without them, they fell into disuse. As the practice of setting through to obtain production by casing perforation came into being, the casing cementing job became of even greater importance.

The fact of soft cement below a top plug and around the casing adjacent to lower perforations, frequently resembling only the drilling mud, gave a lead to use of a bottom plug. Research developed not only improved bottom plugs, but better top plugs. Field tests proved that the bottom plug was the key to the secret. With mud wiped out of the casing ahead of the cement, none was left to accumulate under the top plug. In conjunction with this came better surface equipment to handle two plugs rapidly.

Effects of Drilling Muds

Drilling muds and their effects on all kinds of cementing have been the subject of much study. Very constructive research by numerous laboratories has shown that mud cakes on bore hole walls are one of the prime causes of unsatisfactory casing cementing jobs, therefore, today we see the use of mechanical abrading devices attached to the casing to clean up the well bore and allow cement to adhere properly to the formation itself. We know that the cement alone, within any practical limits of rate of flow, will not clean away these mud cakes to the fullest desired extent.

Electrical methods for bore calipering and continuous temperature surveying were developed. These played a large part

The Author

in cementing progress. The information obtained with such devices finally cleared up the problems of proper volumes of material and the fill-up tops so produced behind casing.

Cementing equipment across 20 years has shown some remarkable changes. A power-driven cementing pump of 1933 would function at about a maximum of 3,500 psi. Such a unit had a gasoline engine developing about 70 hp. Power-driven units today are capable of over 10,000 psi, utilize diesel engines of up to 300 hp and incorporate torque converters, automatic transmissions, pneumatic controls, and numerous other mechanical improvements.

While steam-driven pumps are not in wide usage today, they, neverthless, were important factors in the past two decades. Prior to 1933 steam cementing units carried two pumps. Later, a third pump was added and the three arranged for compounding. With such units, pressures up to about 4,500 psi could be obtained. Still later, new pump designs were evolved, which, with combinations of four and five pumps, provided over 10,000 psi.

Bulk Handling

Up to 1940, practically all of the cement used in oil well cementing was handled in sacks. The transition from the old cloth sacks to paper sacks, which could be ripped on a sack-cutting table, was the first real improvement. Beginning in 1940, the way was paved for the mechanical handling of cement in bulk. From a limited commercial start in 1941, we have seen the use of bulk cement expand to where now the vast majority of all oil well cementing is done with bulk cement, mechanically handled. It is interesting to note that in 1952 cement so handled in the oil fields of the United States alone amounted to approximately 26,000,000 dry cu ft, or 276,000 tons. This idea resulted in further advantages and improvements. It became possible to blend accurately into the cement in a dry form a wide variety of additives, including bentonite, lost circulation materials, expanded perlites, Pozzolanic materials and chemicals for either retardation or rapid setting. As an accumulative result, it is now possible to tailor-make blends of materials to suit the conditions of the well being worked on.

A worker "finger tests" gel mixture being prepared for use in a fracturing operation.

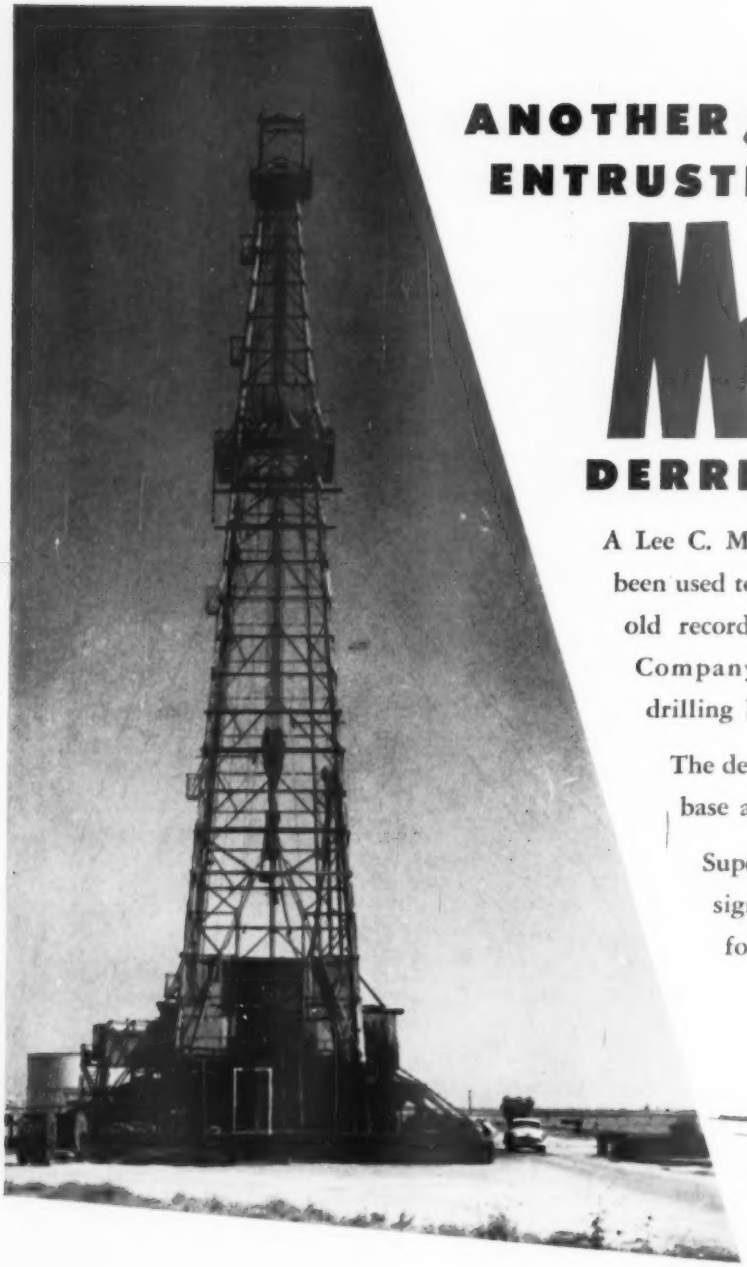
Elevators are put in place to pull drill pipe in a round trip operation in the Lake Washington Field, La.

Within this 20-year span there has been a great deal of research effort devoted to cementing materials and techniques. Laboratory instrumentation has been developed for testing of slurry pumpability under varying conditions of temperature and pressure. The high pressure consistometer and the atmospheric consistometer have disclosed knowledge of the conditions under which cement can be pumped. No longer do we have to depend on the inadequate methods formerly used for setting time. Excellent codes have come into existance for the testing of oil well cements under simulated well conditions. The various API committees and the laboratories of our industry, which have worked on these codes, have given us a standardized set of procedures for guidance in these cases.

A multiude of mechanical devices for all types of cementing work have been designed, tested, proven in practice, and again and again still further improved. They range in such wide variety that it is useless to attempt to list them, but all have played their part in various ways to obtain the prime goal — a better cementing job.

An engineer in the oil fields 20 years ago, be he with a service company or producing company, was frequently not a very respected individual. Neither his opinions nor his presence were the most desirable things around a rig. That is a far cry from today, where, in this comparatively young industry of ours, the technically trained man is consulted in all phases of oil well drilling and producing operations. No, the engineer has certainly not done it all, but no one will deny that scientific knowledge, coupled with practical "know how" has brought our industry a long way — in a short time.

DRILLING



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A Summary of Progress In the Drilling Industry

By

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Perhaps the easiest way to review changes in the drilling business over a 20-year period would be to compare an oil field equipment catalog for 1933 with the same manufacturer's catalog for 1953. The changes are as surprising as would be those indicated by comparing ladies' style catalogs for the same intervals of time, and more striking than would be apparent from a similar examination of advertising for automobiles. Equipment changes, however, are only a portion of the story, therefore, this article will deal with progress in the drilling industry in three main topics: (A) Machinery and Equipment; (B) Drilling Technology, and (C) Personnel and Employee Relations.

Machinery and Equipment

The most obvious change in the surface equipment in the past 20 years is from practically complete reliance on steam equipment to almost universal use of power rigs. The first power rig was produced sometime in the early '30's, and was little more than a "beefed-up" pulling unit. Clutches were manual in operation and of the jaw-tooth design. The usual reaction of the steam driller on seeing his first mechanical draw-works was to remark with some feeling about the "blankety-blank cultivator handles sticking out all over it." These early power rigs lacked many features that today are accepted as commonplace; nevertheless, the fact that they were unitized and could be moved in one compact package definitely set the course of machinery development for the drilling industry. Even manufacturers of steam driven rigs took a lesson from mechanical rig design in that steam rigs themselves became much more transportable. Today, a modern steam rig is an excellent piece of equipment. Its disadvantage lies principally in the fact that it uses a great deal of what has become high-cost fuel. Water consumption of the steam rig is also too high for most areas.

After a rather crude beginning, the mechanical rig has experienced a rapid continuing evolution. Among the early advances was the development of the compounding transmission so that several engines could be utilized to provide the hoist and pump with enough horsepower to perform reasonably well as compared to steam equipment. Another major advance was the wide-spread adoption of air-actuated clutches in which air lines and pressure cylinders replaced manual controls. Still another important change was the water-cooled drum, introduced in 1937.

The last two or three years have seen increasing acceptance of fluid couplings, torque converters, and electro-magnetic couplings. These devices are installed to replace engine clutches, their function representing an attempt to regain some of the flexibility and other desirable operating characteristics of the steam rig.

So far as surface drilling equipment is concerned, the real advance in the 20-year period has been in the relative ease of rigging up, dismantling, and moving the machinery. Only since about 1946 has sufficient horsepower been generally used to enable the power rig to compete on an even basis with a well-equipped steam rig so far as "making hole" is concerned, and only in the past three or four years have power slush pumps been available with sufficient power input capacity to enable drilling to be done with what might be termed "real efficiency."

The foregoing discussion considers the drilling rig as a package and the countless advances in surface equipment, such as jackknife drilling masts, auxiliary brakes, air slips, weight indicators and instruments, etc., have not been discussed although each item has been important.

Genuine progress has been made in the design, metallurgy, and tooth pattern of drilling bits. Rock bits, specifically adapted to the drilling of almost any type formation likely to be encountered, are available. Bit bearings have been improved immeasurably, allowing the use of heavier bit loadings, that is, the weight on bottom has been greatly increased. Recent developments in specialized bits include diamond bits and coreheads for pentrating extremely hard abrasive formations and the so-called "button bit" for drilling chert. The application of hydraulic studies to bit design has cul-

The Author

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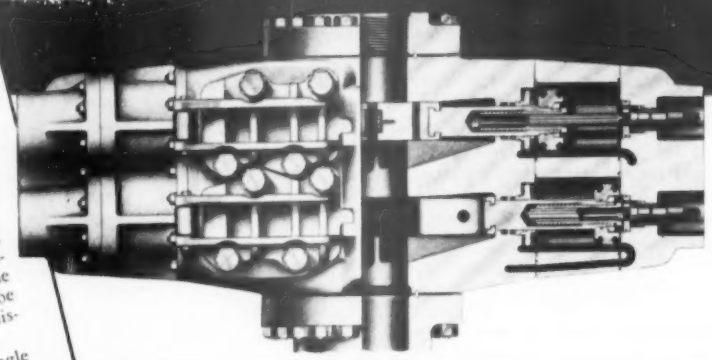

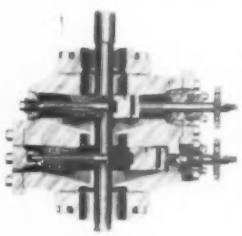

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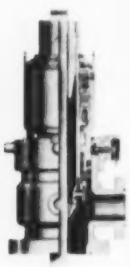

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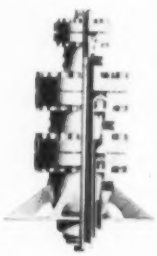

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minated in the jet bit which, coupled with sufficient pumping capacity in an engineered application, can give surprising penetration rates in the softer formations.

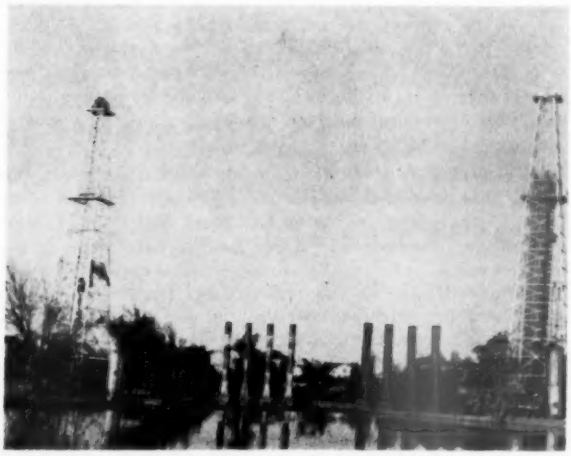
Twenty years ago the drilling string consisted of drill pipe with a short adapter or substitute to enable the drilling bit to be screwed on to the bottom joint of drill pipe. This short adapter became known as a drill collar and the term is still in use although drill collars today bear little resemblance in function or appearance to those of 20 years ago. Most drill collars today are approximately 30 ft in length with bore rangings from $1^3/_4$ in. to about 3 in. The outside diameter of the collars (other than for special jobs) ranges between 6 in. and 8 in; thus it can be seen that the drill collar is a thick-walled steel tube, exceedingly rigid and heavy. From 15 to 25 of these collars may be assembled in the drilling string immediately above the drilling bit, thus providing the weight necessary to attain today's rapid drilling rates.

In 1933 a more or less standard procedure was to drill a $12^1/_4$ in. hole with $6^5/_8$ in. OD drill pipe. The advent of the under-powered gas or diesel rig caused hole size and drill pipe size to be reduced so that for many years $4^1/_2$ in. or $3^1/_2$ in. OD drill pipe has been generally used in 9 in. and $7^7/_8$ in. hole sizes. The availability of large pumps and increased horsepower has only recently begun to cause a trend back toward larger pipe sizes in order to obtain better hydraulic efficiency. The writer expects this trend to continue for our present drill pipe hole size practices do not appear to equal the penetration rates possible in many areas if the large pipe of the early '30's and our present day techniques were combined.

Drilling Methods

The most important single event in the past 20 years so far as drilling technology is concerned, was the development of the science or art of mud engineering. From the first rotary drilled hole at Spindletop in the early 1900's to about 1930, mud was what came out of the hole after water had been pumped into it through the drill pipe.

If the contractor could scrape up a little clay and mix it into his circulating pit, he would sometimes do so and observe that beneficial results were obtained. Fortunately for rotary rig contractors in those days, depths were relatively shallow and if the contractor was lucky he could usually manage to get his hole down. Since about 1930 an entire profession has grown up, devoted to prescribing various chemical and mechanical additives for drilling fluids. The objective is that the mud should have the best specifications to meet the problem encountered in the specific hole at that particular time. Just as a doctor may have to treat a patient for measles and on another occasion for tuberculosis, the mud engineer at one time may attempt to provide a drilling fluid allowing maximum drilling progress and later when the hole nears completion he may emphasize a specification for low water loss, so that contamination of the potential oil or gas formation is minimized.



Steam rigs drilling 6,300 ft. wells in the Oklahoma City Pool, 1936. Reserve Pit in foreground.

The development of the mud business leaves a little to be desired from the standpoint of economics, in that mud engineering services are usually furnished by the sales agent for the chemicals and materials used. Naturally, this is not conducive to greatest economy. Nevertheless, the various mud companies render invaluable service to the petroleum industry and drilling present day deep wells would be an impossibility without precise mud control.

For years it was thought that increased drilling weights (weight on bottom) would improve penetration rates. Before this idea could be given a good trial, bits had to be developed capable of sustaining the increased load, and it was necessary to learn that sufficient drill collars should be used in order that drill pipe could be kept in tension at all times. Thus it was only in 1946 that heavy drilling weight, utilizing 20 or more drill collars, were generally adopted. This development has increased drilling rates in hard formations by a factor of two or three. As a side-light on this development, many drilling contractors learned that long drill collar strings reduced the depth capacity of their drilling rigs, for 20 drill collars create the same hook load as does approximately 4,000 ft of $4^1/_2$ in. drill pipe.

It should be mentioned that many problems are still unsolved despite intensive study by the industry's most able engineers. Among these problems are those variously associated with the term "lost circulation." Another problem is that of the "crooked hole," for considerable drilling activity is located in areas of rather intense sub-surface folding or deformation. Such conditions tend to cause the hole to go off vertical. Although various palliatives are in more or less common use, the basic problem of the crooked hole is unsolved.

Manpower

All of the changes and improvements in machinery and methods would be meaningless if competent manpower was not available for the proper operation of equipment, and for effective use of present day methods. A modern, up-to-date rig operated by unskilled or careless personnel would compare very poorly in performance with a properly handled 1930 model steam rig. In other words, the most significant advance has been made in training and utilization of manpower.

The 20 men who operate and maintain an average drilling rig earn nearly $11,000 per month, averaging almost $550 per month each.

In addition, some contractors now provide their regular employees with retirement pensions and life insurance and nearly all have hospitalization and medical expense insurance plans covering the employee and his family. These wages, salaries and extra benefits are excellent for workmen who by and large have not had the advantages of higher education, but it must be pointed out that rotary rig workmen earn every penny. Each works seven eight-hour days per week, rain or shine. Crew men must get to the job, no matter where the rig is located, without reference to the condition of roads. Incidentally, the figures cited do not include management salaries or home office overhead.

Present day drilling company employees are solid citizens. They are family men, they pay their bills, and go to church. They are leaders in civic clubs, active in worthwhile projects and are accepted as valuable members of the community in which they live. The term "rough neck" no longer has any validity insofar as it is applied to the character or reputation of drilling people. It is a fact that drilling has become such a complex operation that the contractor just cannot afford to have low-class workmen on his payroll.

It appears that there are two reasons for this improvement: (1) Operating companies, themselves, that is the customers of drilling contractors, have succeeded in attracting high-class personnel, men with engineering training or similar qualifications. These better-trained men have demanded and received better performance. This is an exact parallel to the manner in which the public as a whole has demanded better gasoline, which the refining industry has furnished. (2) The second reason lies in the efforts of progressive drilling contractors to improve their own operations. Such attempts are best illustrated by the manner in which leading drilling contractors formed the American Association of Oilwell Drilling Contractors in 1940.

This Association is not and has never functioned as a price-fixing group, as drilling prices in the past 12 months will conclusively show. The real value of the Association is in its program for education and training, although its work is divided into several committees dealing with different types of education. For example, the Association's Safety Committee sponsors industry-wide safety clinics through which safer operating techniques are made available to all members. As a direct result of this work it is a rare event to observe an unguarded chain or other safety hazard around a drilling rig and many contractors employ full-time safety engineers. The Educational Committee of the Association has trained over 16,000 operations-level employees through mud schools, instruction courses on engine maintenance and operation, and short courses dealing with special subjects typified by an educational film on handling and running casing. The Accounting Committee has published a manual for standardizing accounting practices which has become a reference for the industry. The Drilling Practices Committee is a forum in which better, more economical practices are discussed and publicized.

Through individual subscription, Association members have financed studies at institutions such as Battelle Memorial Institute, which investigated the causes and recommended procedures to minimize the effects of corrosion on drill pipe in certain areas. The Association developed a manual known as "A Primer of Oil Well Drilling," over 20,000 copies of which have been distributed in less than two years, and copies of the manual will be found in the "knowledge box" of many drilling rigs.

All of these activities and many others have provided an environment in which the intelligent, careful workman finds himself at ease. He finds that painstaking efforts are appreciated; that his supervisors give him that recognition which means so much to every one of us.

It is evident that efforts to improve drilling performance have had a tremendous cumulative effect, for it is a fact that since the end of World War II drilling speed has increased about 50 per cent. The cost to the operators for drilling a foot of hole today is less than were costs in 1938 or 1939. It is doubtful that any other billion dollar a year industry can make this same claim.

The writer has no crystal ball, nevertheless, a few predictions concerning future trends in the drilling industry appear worth presenting. Indications are that while specific solutions to individual problems will be worked out, drilling machinery as a whole is likely to retain much of its present form. The basic equipment items, such as derrick, hoist, pumps, and prime movers, will not be eliminated in the foreseeable future. It is likely that rigs for oil field development will be designed to utilize greater horsepower per foot of depth rating than is presently the case. As a rough example, perhaps the 1,000 HP rig now considered satisfactory for drilling in the range of 10,000 ft to 12,500 ft, in the future will be applied to 7,500 ft to 9,000 ft operations. This change will enable the use of larger drill pipe, heavier drill collar strings and larger bits with stronger bearings and bit teeth. Such a rig, although representing a large investment, would result in over-all lower cost when a substantial oil field is being developed. On the other hand, a genuine need exists for highly portable slim-hole rigs to be used for exploration in the 10,000 ft to 15,000 ft range. Such a drilling rig would become the tool of the exploration geologist in the same manner as is the seismograph today. This equipment would be designed for minimum cost, maximum portability and possibly will resemble its big brother, designed for pool development only in a general way.

Heavy Power rig drilling below 14,000 ft. in Elk City Pool, 1953.

The manner in which petroleum engineers and geologists were accepted by the oil producing industry beginning in about 1930 is well known; many top production executives nowadays have engineering or geological backgrounds. Most of these men remember the difficulties encountered in adjusting themselves to the field men for whom they worked when first employed. The drilling industry has lagged in comparison with the production company in the use of engineers as operating men, but a trend has developed which likely will represent a real job opportunity for the young engineer insofar as a lifetime career is concerned. This trend duplicates the employment experience of the production industry in the decade of the 1930's. Unquestionably considerable economy and efficiency can result when engineering principles are more thoroughly blended with the hard-won experience of today's practical drilling superintendents.

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Directional Drilling Today

By

Gordon Jackson

Vice-President, Eastman Oil Well Survey Co.

Member AIME

Directional drilling today is a vastly different enterprise than was the struggling new service of directional drilling 20 years ago. Today, controlled directional drilling is a widely used drilling practice, both in this country and in foreign fields; and we find that the number of large scale directional drilling programs, foreign and domestic, increase each year.

The application of directional drilling, and the associated service of well bore surveying, is a relatively old science which dates back many years in mining technology. However, in oil field drilling practices what we know as controlled directional drilling is a relatively young service which started about 20 years ago.

Twenty years ago, directional drilling, its applications and its theories, were quite novel and were not widely used. Now, however, in 1953 the directional drilling service field has become a well established and accepted service industry which is operated by large, reliable and world-wide companies.

Originally, directional drilling was thought of as a service used only to solve unique problems such as drilling to inaccessible off-shore locations, controlling a wild well which had blown out during drilling operations, and for the drilling of wells under factories, cities, and rivers. The first applications for this new service were of a type wherein directional drilling was the only solution and where the well could not be drilled in any other reasonable manner. This particular type of application still exists and has provided the oil industry with a means of producing oil which otherwise could not be produced. In addition, it was the demand for this type of service which actually started the directional drilling industry.

However, at the present time, the majority of directional drilling operations are not those where directional drilling is the only solution, but actually those where directional drilling is the most economic method to drill to the producing horizon. Controlled directional drilling is now used to save the operator money and is an economic consideration in both slant and vertical drilling. It is widely used for side-tracking, straightening of wells that have become crooked, and for the deflection of the lower portion of wells to producing areas after original bore had missed production. Many times economic savings are indicated by the drilling of slanted wells which are closely grouped at the surface in areas where surface locations are unusually expensive. In other words, modern directional drilling has provided the oil well driller with a tool which he uses in his planning of a drilling program, as a means to drill his wells more economically.

The effect of directional drilling on production technology is appreciable, and many interesting investigations and conclusions concerning the production capacity of directional drilled wells have been made. The study and development of means and tools to accurately direct wells to a distantly removed sub-surface location has had a beneficial effect on the development of other drilling practices normally considered to be routine. Many of the basic concepts of directional drilling of slant holes wherein stabilization of the drill string was the important factor have been utilized in the study and development of methods to drill vertical holes. Much of the basic material concerning the allowable limits of "doglegs," or bends, in well bores were a development of directional drilling concepts and field practices.

The necessary accuracy for modern directional drilling has forced a steady improvement in the sensitivity and reliability of oil well survey instruments. Modern survey instruments are easy to operate, reliable and accurate in their recordings of direction and drift angles, and their use has added a great deal to our understanding of the effects of changes in the course of the well bore while the well is being drilled. Accurate surveys and the proper analysis of the effect of bends, or "doglegs," have given a better understanding of their effect on the production cost after the well has been completed.

The large oil reserves now thought to be located under "off-shore" or tideland areas were first brought to public notice, and their importance first given emphasis, as a result

The Author

Fig. 1 — Wellhead installation for deep directionally drilled wells.

of wide and successful directional drilling of shoreline wells. The interest in off-shore oil deposits has steadily increased until it has reached its present prominent position in any consideration of the oil reserves of this country. The evaluation of the off-shore problem is, at the present time, very closely tied to the economic planning of directional drilling operations. The future will probably show a greater application of directional drilling in tideland development provided that the operations are economically sound.

Directional Drilling Achievements

Directional drilling is a large and growing industry. In 1953 it is estimated that there will be four million feet of well bore deflected under the supervision of directional drilling engineers, and many more million feet where control vertical drilling will be necessary. There are a number of examples where drilling programs involving a hundred or more slant wells in unit operations were completed and successfully put on production, as shown in Figs. 1, and 2. Many large directional drilling programs, including hundreds of wells both here and abroad, are being studied for action at the present time.

The growth of directional drilling applications percentage-wise has been most outstanding in the California area, where directional drilling as a service started 20 years ago. During the period from Jan., 1953, to June, 1953, over 20 per cent of the total wells drilled in California were directionally drilled. On the other hand, while the over-all percentage of directionally drilled wells to the total wells drilled in the Gulf Coast has been lower, the actual total number of directional drilled wells is greater in the Gulf Coast than in any other region. In every area the percentage of directed wells is increasing and the total number of wells deflected is at an all-time high.

As an example of a 1953 accomplishment in directional drilling, the following statistics for a well deflected under the Pacific Ocean are given, and a sectional view is shown in Fig. 3.

The total depth was 11,440 ft, the vertical depth was 4,240 ft, and the horizontal deflection was 10,244 ft. The maximum angle from the vertical was 75°, the well was drilled in 49 days and completed as a good producer. The average rate of penetration was 235 ft per day.

In the Gulf Coast region, much emphasis has been placed on planning in advance for directional drilling jobs, which has resulted in some outstanding examples of improvement in penetration rates on deflected wells. It is true that the following two examples are exceptionally good, but they do show what has recently been accomplished by utilizing past experiences. In South Texas, a well was drilled at an average angle of 10° 20′ for a total footage of 8,233 ft, with an average footage per drilling day of 367 ft. There were five deflection tools set on this well. A southern Louisiana well was drilled for 6,025 ft at an average angle of 15° and at a rate per drilling day of 357 ft. There were two deflection tools set on this well.

These three examples demonstrate that not only can wells be deflected long distances, but they can be drilled directionally in very fast time. High penetration rates are now possible in well planned programs.

Directional drilling procedures have been adapted to a number of new oil well drilling techniques. As an example, the operations with gas drilling raised a great many questions as to the practicability of directional drilling where gas is being used as a circulating medium. Among the many problems were the fact that the hole sizes were small and the penetration rates very high. Directional drilling operations have been undertaken on at least two dozen wells with good success. The milling of casings and the setting of permanent whipstocks is now a routine practice in gas drilling. The recompletions by this method are fast, economical, and have certain production benefits of an engineering nature. All types of deflection tools have now been adapted to gas operations and the well bores are deflected and surveyed with the same efficiency as if mud fluid was used for circulating.

Controlled Vertical Drilling

Vertical drilling, or the study of keeping the well as near vertical as possible, is in a sense directional drilling, inasmuch as keeping the well bore from changing course and stabilizing it in a vertical position is a directional problem. In fact, an important feature of directional drilling

Fig. 2 — Large multiple wellhead installation with production units closely spaced. These are high angle wells slanted under the tidelands.

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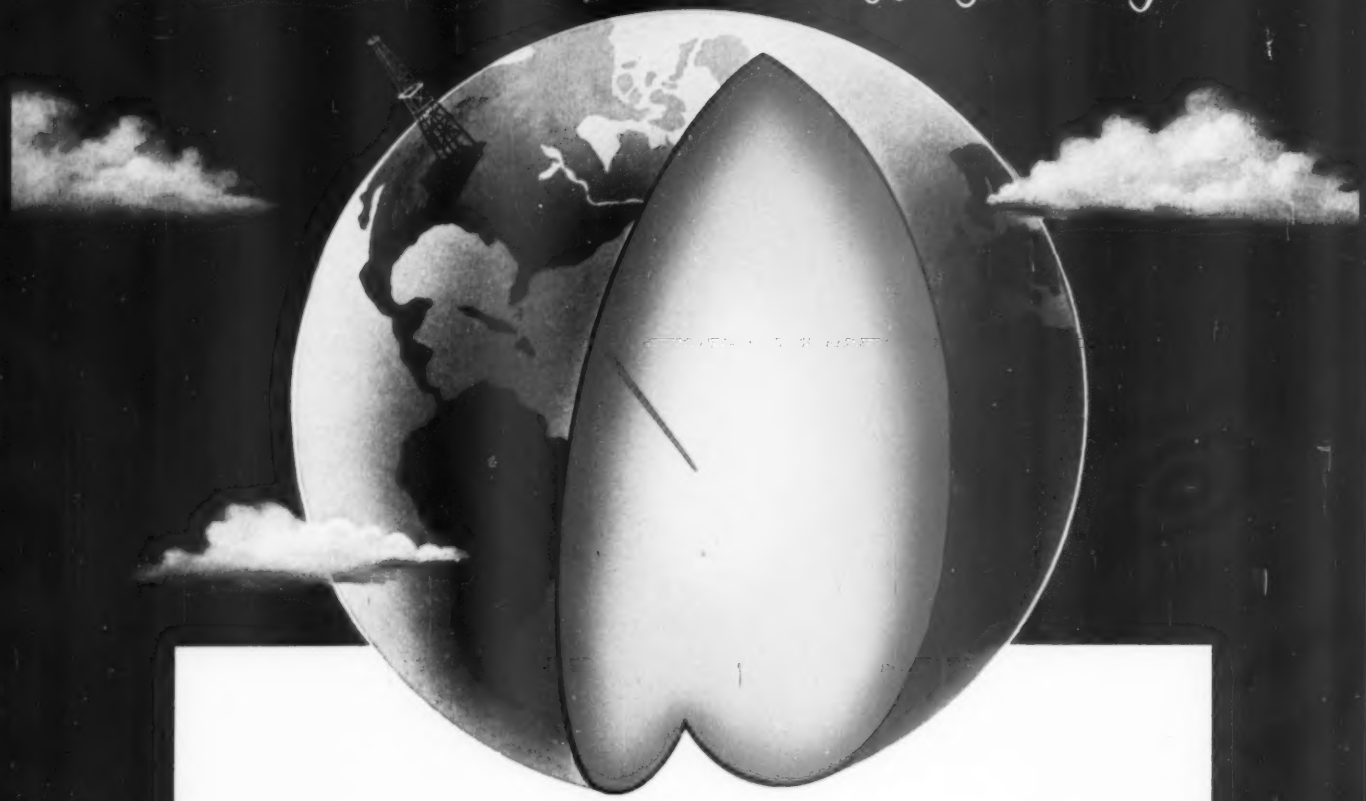

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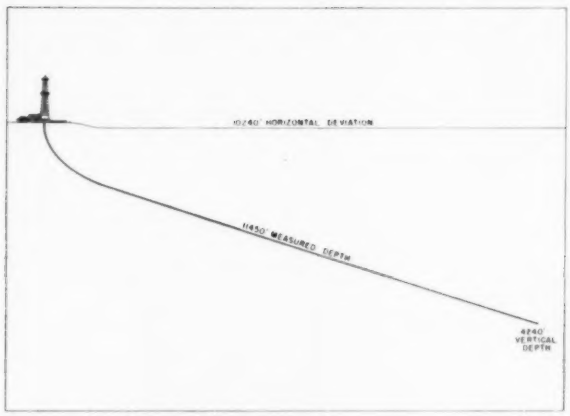

Fig. 3 — Cross section view of a high angle well under the ocean with a drift of 75°.

is the ability to stabilize the course of the well in any desired position. In recent years there has been a great deal of time and effort given to the study of keeping the bore vertical and there have been some outstanding developments. Many of these developments have been made through very theoretical and practical studies in the use of stabilizers, reamers, and oversize drill collars. The use of this equipment has allowed the application of large weights on the bit without buckling the drill string and thus causing the well to deviate from vertical. The results of these studies have also helped to minimize the size of the dogleg caused by changes in course of the well bore. However, in spite of the best efforts to maintain the drift angle of the well as low as possible, the well will many times gain drift if enough weight is applied to reach an economic rate of penetration.

At the present time, there is a tendency on the part of many operators to not over-emphasize the importance of the actual angle of inclination, but to study the possibility of minimizing and controlling the size of the doglegs, thus allowing the well to assume a reasonable drift angle. This is truly a directional drilling procedure put to use in the drilling of a vertical well. If the well exceeds a reasonable angle, the operator has before him two economically feasible courses: the well can be straightened by use of directional tools and directional drilling methods, or the well can be surveyed as it is being drilled and if it is drifting too far from the proposed bottom hole location, it can be deflected back to the bottom hole location.

Many times it is more economical to use directional drilling to put a well back under the desired location than it would be to hold up on the drilling weight in order to keep the well close to vertical. Also, by surveying as the well is progressing, any unusual doglegs can be detected and reaming undertaken to minimize the possibility of key seats.

Directional Drilling Tools

The start of the service company phase of directional drilling was an actuality when the removable whipstock was invented and a single shot survey machine developed. These two inventions were the tools which allowed the directional drilling engineer to change the course of the well bore when it was not proceeding in the proper direction and at the proper angle. The removable whipstock is still the most basic deflection tool used in directional drilling operations. Almost all other deflection tools, with the exception of the Lewis type knuckle joint, are to some degree a modification or a combination of other tools with a removable whipstock. The modern whipstock and its accessory tools are therefore primarily improved versions of the original tools. However, the results gained from modern tools are naturally better than the original deflection tools.

Directional drilling practices and the standard of directional drilling equipment has kept up in every respect with the advancements made in other phases of oil well drilling. Directional drillers are alert to any possibility of saving drilling time, and have, therefore, taken advantage of all new methods of drilling. Careful study and the application of the best methods for the particular job have resulted in penetration rates which compare very closely with normal drilling rates. The directional drilling industry is constantly striving to still further reduce the average difference between a slant hole drilling time and a straight hole drilling time. All directional operations and tools are now designed to be most efficient for a particular area and are able to use the proper rock bits and diamond bits most suitable to the formation being drilled. The surveying of the well while it is being drilled is usually accomplished by the use of a K-Monel non-magnetic drill collar and standard oil well surveying instruments. The use of non-magnetic drill collars allow complete multiple shot surveys, or single shot surveys, to be made without drawing the drill pipe from the well to run the instrument. Bottom hole orientation whereby the deflection tool is oriented after being lowered in the well bore by instruments run through the drill pipe is now a universally accepted orienting means to face the deflection tools in the proper position.

CONCLUSION

The present trend of directional drilling engineering, as in the case of any forward moving service industry, is toward exact thinking and planning of directional drilling programs. There is an alertness to all means of improving techniques and taking prompt advantage of new developments. Directional drilling is on the threshold of being competitive with any other class of drilling, and the future will see many more opportunities for directional drilling applications.

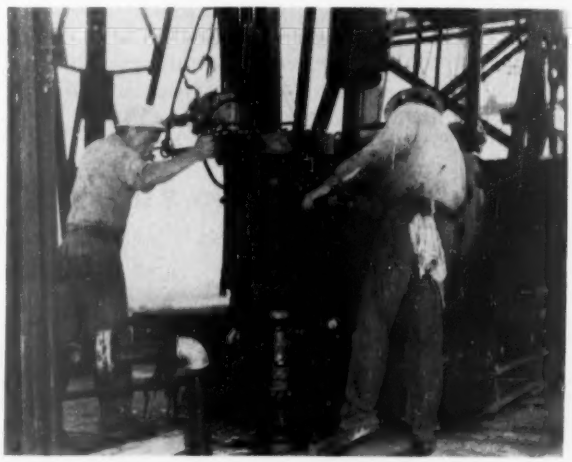

Fig. 4 — Working over a well slanted under the tidelands.

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Two Decades of Electrical Logging

By

H. G. Doll

Chairman of the Board and Director of Research
Schlumberger Well Surveying Corp.

Member AIME

The present paper, written at the request of the editor of the JOURNAL OF PETROLEUM TECHNOLOGY, gives a brief history of the various logging methods and of their progressive development during the last 20 years. More generally, it refers to the different operations performed in drill holes at the end of an electric cable to locate the permeable formations and to determine their characteristics, such as porosity, fluid content, and dip; to procure samples of the formation by sidewall coring; and to determine data concerning the drill hole itself, as, for example, its diameter and deviation from vertical.

ELECTRICAL LOGGING

Correlation and Bed Thickness Determination

The first log in an oil well was made in 1927 and comprised only a resistivity curve. The sharp contrast in resistivity from one bed to another suggested that such a log would be very useful for correlation between wells, a conclusion that was confirmed by field experience. In 1931, the SP log was added. This parameter not only improved the qualities of the electric log for correlation purposes, but made it possible, in many cases, and particularly in soft formations, to locate permeable beds and to determine their boundaries with reasonable accuracy. The combination log, comprising one resistivity curve, generally a short normal, and the SP log, was introduced commercially in the United States in 1932 and was immediately recognized as a very valuable tool.

First Attempts at Quantitative Analysis

Until about 1937, the application of electrical logging was, in many cases, limited to correlation and bed thickness determination. During that period, however, attempts were progressively made to detect oil sands by qualitative interpretation, especially by comparing the resistivity of a given permeable bed in different wells drilled in the same field. This resulted in valuable conclusions in many cases, and also brought to light the important influence that mud filtrate invasion has on the apparent resistivities as measured in the drill hole.

Around 1938 the problem of quantitative interpretation received increased attention, when the first paper dealing with that problem was published. From there on, not only the service companies, but the oil companies themselves, did extensive work to improve the interpretation. Subsequent papers discussing empirical relations between formation factor and porosity, and between resistivity of the uncontaminated part of a permeable bed and its oil and water saturation, brought important and basic contributions to the problem of quantitative analysis.

The electric logs available at that time did not measure separately the resistivity of the invaded zone, and therefore, did not allow the determination of formation factor and porosity. On the other hand, it was generally not possible to determine oil and water saturation because the true resistivity, R_t, of the bed was not given by a single resistivity curve. The bore hole diameter, resistivity of the mud, and invasion of the permeable bed by mud filtrate all contributed to make the apparent resistivity as measured by the single curve substantially different from the true value.

This last difficulty was fairly easy to overcome in the case of thick beds not too deeply invaded, as frequently encountered in sand and shale formations. In that case, the use of longer spacings, normal or lateral, made it possible to read the value of R_t directly from the log. The short device previously used was kept, however, if only for correlation purposes, and this led to the standard electric log with three curves: one

The Author

SP curve, and two resistivity curves. Later, a fourth curve was added, generally a long lateral.

In cases of substantial invasion by mud filtrate, none of the curves would, however, read R_t directly. This situation was remedied by the use of multiple spacings, and the combination of their different readings through departure curves. This solution, however, was not perfect, and in any case the first departure curves that were published applied only to thick beds.

Even though the determination of R_t was seldom easy, there were enough instances where R_t could be sufficiently well determined and where, therefore, attempts at quantitative interpretation could be made. Since it was not possible to derive the formation factor from any of the logs available at that time, the water saturation S of a given oil sand had to be derived from its resistivity R_t and from the resistivity R_o of its water bearing section or of an adjacent water bearing bed. This approach was, of course, justified only if it could be assumed that the porosity and connate water salinity were the same at the two levels where R_t and R_o were respectively determined. This more or less limited the use of the method to unconsolidated formations where these two conditions are frequently satisfied. Furthermore, the method applied only to substantially clean sands, since in shaly sands the relation between S, R_t and R_o further depends on the shale content.

At the end of the war, the problem of correlation was fairly well solved in all types of formations. Location of permeable beds and determination of their thickness were well enough solved in unconsolidated formations, but left much to be desired in hard formations, especially where salty muds were used. Oil and water saturation could be determined only in clean and unconsolidated sands, and porosity could generally not be derived from the logs because there was no way to determine, with enough accuracy, the resistivity of the invaded zone.

Post-War Developments in Electrical Logging

The war slowed research and development efforts, because the activity of the research departments of service companies and oil companies had to concentrate mostly on military work.

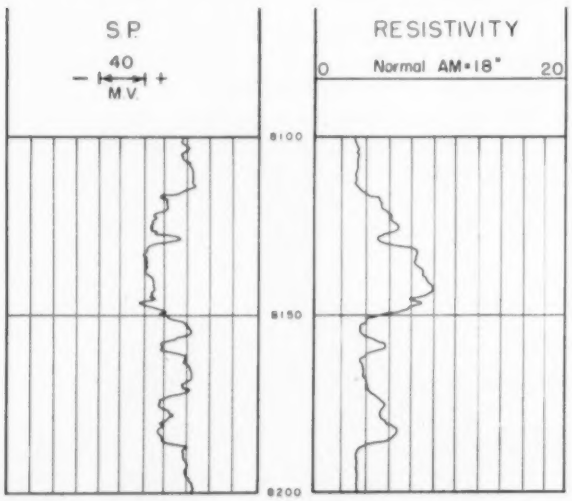

Fig. 1 — Example of an early hand-recorder log made in 1936. The survey consisted of only two curves, which had to be retraced after the recording.

Immediately after the war, research activity was resumed. For electrical logging, the first step was to develop a system of simultaneous recording of the four curves that had become standard in most territories. Concurrently, great efforts were made to improve the interpretation of the existing logs by a theoretical study of their behavior for various conditions. This resulted in a substantial number of publications concerning either the SP log or the resistivity logs. For the latter, departure curves were issued, first for thick beds, and later, after a tedious computation, for beds of finite thickness. These theoretical studies remedied substantially the limitations of the logs, but not enough to really allow for quantitative interpretation in the general case. They also brought to light the improvement of the resistivity logs which would result from the use of muds whose salinities approach that of the connate water.

Since the old logging methods were fairly satisfactory in unconsolidated formations, research efforts were mostly applied to problems which still had to be solved in hard formations, where the conventional logs did not even give a satisfactory answer to the detection of permeable beds or the accurate determination of their boundaries. A better understanding of the SP log in hard formations, resulting from the publication of a theoretical study of this log, had substantially improved the situation; but the determination of the permeable beds in hard formations remained difficult and frequently inaccurate.

Detail Logs for Very Shallow Investigation

A very important step in electrical logging occurred in 1948 when the MicroLog was introduced. This log solved simultaneously the problem of measuring the resistivity R_{xo} of the invaded zone and that of detecting the permeable beds.

As a means to determine the resistivity R_{xo} of the invaded zone, the MicroLog has been successful in formations whose porosity is not much smaller than 20 percent. For formations of lower porosity, the high resistivity ratio between the invaded zone and the mud cake makes the determination of R_{xo} frequently inaccurate, because of congestion of the curves in the corresponding region of the interpretation chart. More accurate values of R_{xo} fortunately are obtained in formations of low porosity by application of a new technique called MicroLaterolog.

This accurate determination of R_{xo} is important. First, it is one of the essential data that are needed to derive the value of R_t from the apparent resistivities measured by the other electric logs. Secondly, R_{xo} leads directly to the formation factor and to the porosity, at least for formations which are substantially free from interbedded shale streaks and disseminated clay, and provided the residual oil in the invaded zone behind the mud cake can be estimated.

To determine the formation factor or the porosity from the value of R_{xo}, as derived from either a MicroLog or a MicroLaterolog, it is necessary to take into account the resistivity of the mud filtrate which can easily be measured on a sample and corrected for hole temperature. Comparisons of porosity determinations derived from the logs against core analysis have been made in many cases and have established the reliability of the method in clean formations.

The MicroLog, usually associated with an SP log or a gamma ray log, or both, has been an invaluable tool for the accurate delineation of permeable beds, especially in hard formations where the SP log alone is not sufficient. Today, the

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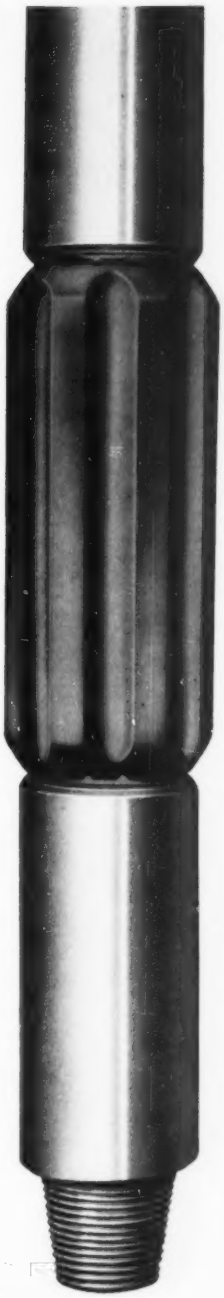

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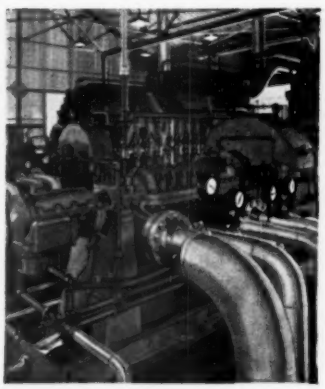
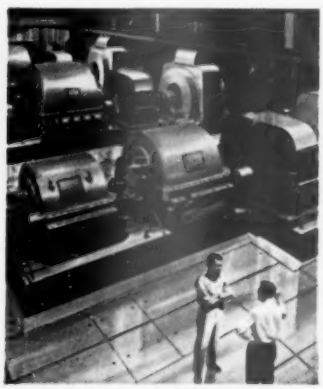


PACIFIC PUMPS, INC., Huntington Park, Calif. Centrifugal pumps, deep oilwell plunger pumps, hot oil and boiler feed pumps.



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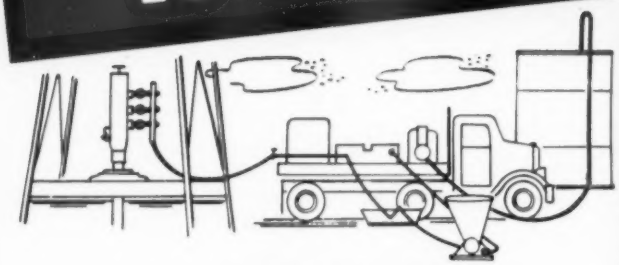

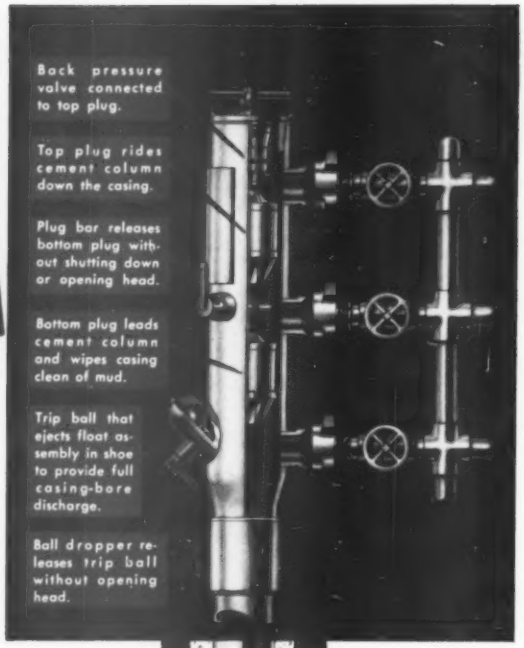
Back pressure valve connected to top plug.
Top plug rides cement column down the casing.
Plug bar releases bottom plug without shutting down or opening head.
Bottom plug leads cement column and wipes casing clean of mud.
Trip ball that ejects float assembly in shoe to provide full casing-bore discharge.
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MicroLog, or its close relatives, the Contact Log and the Microsurvey, are almost systematically used in hard formations, and are even gradually invading the sand and shale territories.

Focused Logs for Deep Investigation

The focused logs, which provide deep investigation, are Induction Log, Laterolog, and Guarded Electrode Log.

With somewhat different focusing properties and a smaller depth of investigation, the Pseudo-Laterolog recently introduced is particularly sensitive to the thickness of the invaded zone. It, therefore, affords a way to estimate the influence of the invaded zone on the measurements made by the other logs.

The most important property of these focused logs is probably that they are substantially free from the short-circuiting effect of the mud column, which all but flattened the old type resistivity logs in highly resistive formations, especially where the mud was salty. These new logs are also much less influenced by the surrounding formations. They can, therefore, measure resistivities with more accuracy, even in beds that are not very thick.

The Induction Log, which is the only existing electric log that can be properly recorded in both oil base and water base mud, has also the advantage of being much less influenced than other logs by invaded zones that are more resistive than the uncontaminated zones behind them. It is, therefore, very useful in cases where the mud resistivity is substantially higher than the connate water resistivity. It is much less influenced by thin resistive beds, such as lignite, interbedded with producing sands, as are encountered, for example, in Mississippi, and on that count has an important advantage over standard electric logs.

The Laterolog, the Guarded Electric Log, and the Pseudo-Laterolog are particularly useful in hard formations, and are at their best when the resistivity of the mud is not much higher than that of the connate water, so that the invaded zone is not abnormally resistive. They make it possible to record accurate and detailed logs in formations whose resistivities may be several hundred times that of the mud filling the hole, and where, therefore, the old resistivity logs could give little more than correlations. Although introduced rather recently, these logs are recorded systematically today in wells that are drilled with salty mud, and their use is being progressively extended, as additional equipments become available, to the wells drilled in hard formations.

GAMMA RAY LOG

The gamma ray or radioactivity log, which records the natural radioactivity of the formations, was introduced around 1940 and has been more and more used ever since. There are two principal reasons for its success. One is that the radioactivity of the shales or shaly beds is generally larger than that of other formations, and, consequently, the gamma ray log gives a contrast between formations similar to the SP log. When the SP log is deficient, as happens in wells drilled with oil base mud, or sometimes in hard formations, or when the mud is very salty, the gamma ray log can be used as a valuable substitute. Another important property of the gamma ray log is that it can be recorded in cased wells almost as well as in open hole. It constitutes, therefore, an invaluable tool for accurate correlation in depth between logs recorded in open hole and operations performed later in the same well once casing has been set.

Another interesting application of gamma ray logs is the determination of potash beds which are highly radioactive. The gamma ray log, in combination with electric logs, is also used for the location of coal beds, whose radioactivity is generally very low.

NEUTRON LOG

The neutron log, which was introduced in 1942, has since received a wide acceptance, particularly in hard formations.

For correlation, the neutron log could substitute for a resistivity log, if need be, and does substitute when logging in open hole is not possible. This, however, does not seem to be its normal field of application, and it is primarily the quantitative properties of the neutron log, as a means of detecting and measuring porosity, which are responsible for its success.

When the formations are saturated with fluid, whether that fluid be oil or water, the neutron deflection can be calibrated in terms of porosity, provided, however, that the formations do not contain too much laminated shale or disseminated clay.

In the case of homogeneous sands, where the porosity is about uniform, the neutron curve can often locate the gas-oil contact.

The gamma ray log and neutron log can be recorded simultaneously, with a saving in rig time.

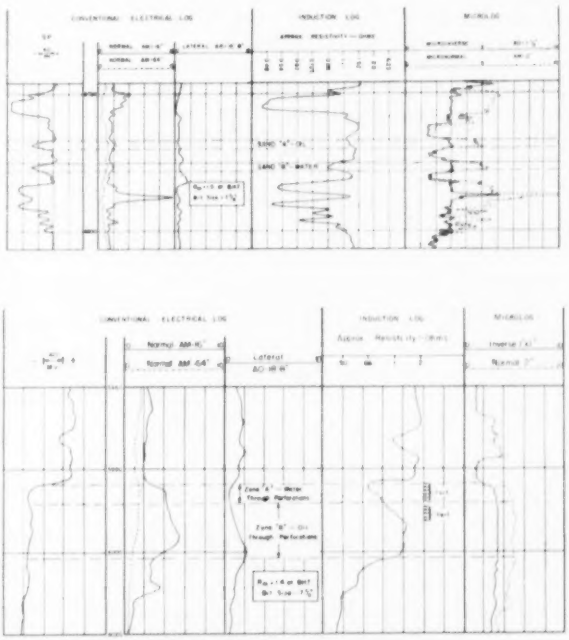

Fig. 2 — (Example 1, top) The Induction log distinguishes Oil Sand A from Water Sand B, an indication not given by the other logs. Note the accurate determination of bed boundaries by the MicroLog. (Example 2, bottom) Water bearing Zone A, distinguished from oil bearing Zone B only by the Induction log, would otherwise have been interpreted as the oil bearing top of a single thick sand reservoir. Evidently Zone A is separated from Zone B by a very thin reservoir discontinuity.

WHERE DOES OIL WELL LOGGING STAND TODAY?

In the early days, a two-curve log, having an SP curve and a resistivity curve, was considered sufficient. It generally gave enough data for good correlation between wells, and made it possible to locate the permeable beds, at least in unconsolidated formations.

Today, much more is requested from logging, and quantitative analysis must be made available whenever possible. For that purpose, entirely new electric logs are available, together with gamma ray and neutron logs. Are these new logs to replace the old ones, or should they be recorded in addition to them? What is the place of the gamma log and the neutron log? Should they be substituted for electric logs, or combined with them for the interpretation?

To give an answer to all these questions, it is necessary to anticipate somewhat, because many of the new logs have not yet been used extensively enough to provide the field experience that could lead to definite conclusions. It seems, however, that the following conclusions can be reasonably drawn as far as the not too distant future is concerned, assuming that no new methods are made available that would revolutionize the problem.

Whatever the type of formation, it is necessary to have a good detection of the permeable beds, and an accurate determination of their boundaries. One of the most accurate tools today, in that respect, seems to be the MicroLog, or a combination of MicroLog and MicroLaterolog, supplemented by the qualitative indications supplied by the SP log, or the gamma ray log, or both.

In addition to the accurate location of permeable beds, the MicroLog-MicroLaterolog combination will give the value of R_{xo}, resistivity of the invaded zone, which has to be known for the interpretation of the other electric logs. It will give, furthermore, at lease in favorable cases, when there is not too much laminated shale or disseminated clay, the porosity of the permeable beds, or, to be more precise, the percentage of water per volume in permeable beds immediately behind the mud cake, from which the porosity can be derived if the residual oil can be estimated.

If only the porosity of the formations has to be determined, the neutron log will generally serve substantially the same purpose as the MicroLaterolog. Which of the two logs, MicroLaterolog or neutron log, is the best for that particular purpose is hard to say, and statistical comparison with core analysis will have to give the answer. However, and even if the neturon interpretation were to be systematically the best, it seems that the MicroLaterolog would remain because it is by far the best to give the value of R_{xo}, which is essential for the interpretation of other electric logs in terms of oil and water saturation. Offhand, and because of the additional difficulties due to residual oil saturation in the invaded zone, and to disseminated clay, the probability is that both the MicroLaterolog and the neutron log will be used concurrently for the interpretation in order to make it safer and more accurate.

The resistivity R_{xo} of the invaded zone having been determined, two more resistivity logs, having respectively deep and moderately deep investigation, are generally needed to determine the resistivity R_t of the uncontaminated permeable formations. Available today for that purpose are the Laterolog, Induction Log, and Pseudo-Laterolog. In unconsolidated formations the standard electric resistivity logs can be combined with the Induction Log.

In sand and shale formations, the addition of the Induction Log seems highly desirable, because it is much less subject to the shielding effect of the invaded zone which handicaps the standard electric logs when the mud is substantially more resistive than the connate water, as is generally the case. The standard electric log will remain, however, at least until it becomes possible to record an SP curve, and one

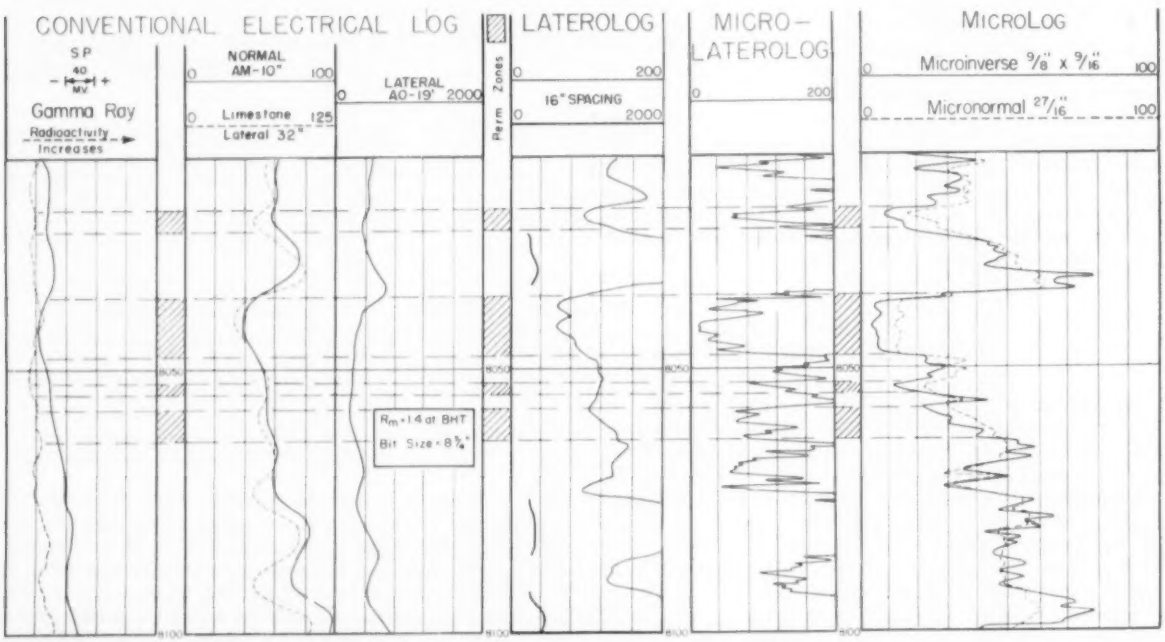

Fig. 3 — Example of a modern log in hard formation territory. Valuable supplementary information is provided by the Laterolog, MicroLog and MicroLaterolog.

resistivity curve, simultaneously with the Induction Log.

In hard formations, two solutions are possible. A combination of Laterolog and Pseudo-Laterolog, which will be at its best when the mud is rather conductive, or a combination of Induction Log and Laterolog, which should be preferred in case of fresh mud, but which would make simultaneous recording more difficult. Here, again, the standard electrical log will still have to be recorded for some time, at least until the Laterolog has been supplemented, probably by the Pseudo-Laterolog, and with simultaneous recording of the SP.

The interpretation with the combination of two of the logs mentioned above, and with prior knowledge of R_{xo} obtained from the MicroLog-MicroLaterolog combination, should be fairly easy, and would not require the use of the complicated set of departure curves that were needed with the older logs.

In the case of oil base mud, the solution is not as complete. The Induction Log, however, which could be run with two spacings, the gamma ray log and the neutron log, can be recorded just as well in oil base mud, and should solve the most important problems in that case.

To compute the value S of the water saturation from the true resistivity R_t of the uncontaminated zone, as derived from the logs, it is also necessary to know the resistivity R_w of the connate water, which fortunately is frequently known by statistics. When this is not the case, an approximate value of R_w can be derived from the magnitude of the SP deflections, at least in the case of permeable formations that are thick enough and do not contain too much interbedded shale streaks or disseminated clay.

The most important problem that has received so far no satisfactory solution is that of shaly sands. When sands contain a substantial proportion of shale streaks or disseminated clay, the resistivities, the SP, and the neutron deflections are all affected, so that the standard methods of interpretation do not apply. Several papers have already been published by various authors on that important subject of shaly sands, and several more are to be presented in the near future.

There are reasons to believe that the various efforts made to study that difficult problem will lead at least to a qualitative solution, whereby it will be possible to determine whether a shaly sand is oil bearing or not. This by itself would be very important. It might be interesting to mention that, in that respect, the use of drilling muds having substantially the same salinity as the connate water, would be a great help.

OTHER OPERATIONS IN OPEN HOLE

In addition to the various logs listed thus far, whose purpose is to locate permeable beds and measure their characteristics as possible reservoirs, several other operations, which can be considered as auxilitaries to logging, are also performed in open hole.

Caliper or section gage logs are used to record the diameter of the drill hole. This information is useful not only to the petroleum engineer, for example, to determine the volume of cement that will be required, but also to the logging specialist as a help for log interpretation. This type of log has been recorded since approximately 1939.

Directional surveys, which measure the inclination of the drill hole at various depths, and its orientation, have been performed on a large scale and with many different equipments. This type of survey is almost as old as logging itself, and the recent efforts in that field have been toward improved accuracy, speed of operation, and possibility of measuring properly in the high temperatures encountered in some wells.

Dipmeter surveys, which determine the direction and angle of dip of the formation, have been run since 1935, but had a slow start. The situation was improved by the introduction of the correlation dipmeters: namely the SP dipmeter in 1941 and the resistivity dipmeter in 1947. More recently, new dipmeters that give a continuous record of the open hole and make it possible to determine dip at a large number of levels, have been introduced and quite favorably received.

One of the most important auxiliary operations accompanying logging surveys is unquestionably the taking of sidewall cores. This type of operation was started in the late 1930's and has developed quite fast ever since, at least in soft and moderately consolidated formations. Most sample takers used in that case are of the gun type, wherein the samples are obtained by shooting into the formation hollow bullets which are retrieved by means of small wires or cables. The more recent tools can shoot as many as 30 bullets in one run, and take cores that are larger than those obtained with the older tools. Satisfactory cores are obtained for an average of 70 per cent of the bullets. In soft formation territory its operation is as routine as electrical logging itself and the combination of electrical log and sample taker has resulted in a substantial increase in drilling speed through the reduction of conventional coring.

Temperature surveys are frequently run either in open hole or in cased wells. In open hole, the most important application, which developed primarily in the recent past, seems to be the logging of wells drilled dry, the purpose of the temperature survey being to locate levels at which gas enters the hole. In cased wells, the most important service rendered by temperature logs is probably the detection of the top of cement behind the casing.

Many other auxiliary operations are performed in open and cased wells, but they have not thus far had any large commercial developments. Among them it is worthwhile to mention the location of water flows, or of lost circulation; velocity surveys, which are necessary in the calibration of surface prospecting work by the seismic method; and magnetic susceptibility logs, which have been introduced quite recently and whose field of application, outside of correlation, still remains to be clarified by extensive field studies. Work has also been done by various experimenters in the field of acoustic logging, and equipments developed for that purpose. This latter type of work is, however, still in the development stage, and it is too early to forecast commercial applications at the present time.

CONCLUSION

Prewar logs were quite good in unconsolidated formations, but they were not satisfactory in hard formations. Entirely new electric logs have removed that handicap, and have even improved the interpretation in sand and shale formations, so that today permeable beds can be accurately located and, except for shaly sands, their porosity and water saturation determined in most cases.

But the progress has not been limited to the introduction of new logging methods or auxiliary operations. Much has been done by the various service companies, often with the cooperation of the oil companies themselves, to improve the quality of the equipment, the speed of operation, and the interpretation of the results.

As a consequence, logging and its auxiliary operations constitute today a set of invaluable tools in oil well drilling.

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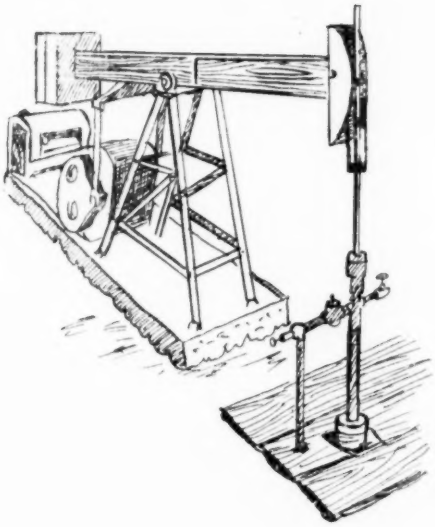

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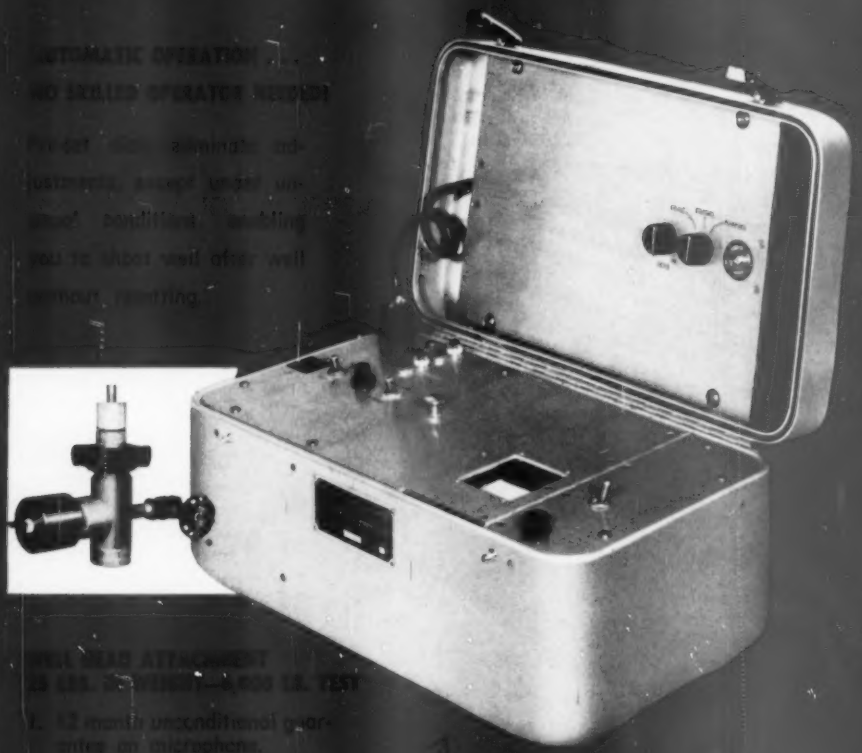

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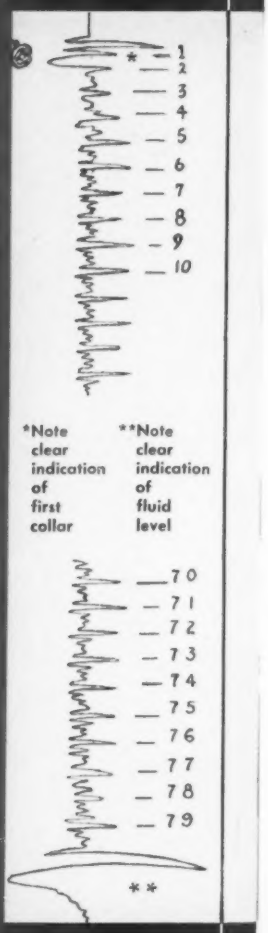

*Note clear indication of first collar

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Petroleum Production Equipment —Twenty Years of Development

By

Carl E. Reistle, Jr.

Director of Production Department, Humble Oil and Refining Co.

Member AIME

During the last 50 years the people of the United States have done more to establish their control over *things* — more to alter their environments better to suit themselves — than all the remaining people of the world have done in all of time.

We must visualize the last two decades of development of petroleum production equipment as a part of this great general increase in the command people in the United States exercise over things. We must recognize that all life and action in our country are a closely articulated whole and that no part changes or is changed without affecting the whole. We live in what appears to be a bewildering complex association of millions of people; yet, all our material progress, which certainly would have seemed fantastic a generation ago, flows from an extremely simple condition. Men have been free to sell the products of their personal and individual efforts to people who want them and who possess the means to buy.

A few minutes of thumbing through oil field catalogs of the past 20 years point up sharply the changes which have come about in some production equipment. We note, also, the many items added, and the numerous items of old equipment adapted to new jobs.

But behind the illustrations and lurking between the pages recording the improvements in production equipment, we see, hazily, the thousands of men who made them possible.

There are the eager inventors and the ingenious, resourceful shopmen. There are the men who bet their life savings that the inventor and the shopmen were right. There is the peddler, discouraged but hiding his discouragement in simulated enthusiasm, shoe soles worn through. There are the field men, critical, doubting superintendents, precise engineers, and the canny pumpers, whose native intelligence so often made things work when others couldn't. Somehow, we tend to see more plainly those men whose perseverance, brains, or luck was rewarded by what we call success. But, mustered in the background and extending as far as we can see, is the host of men we once knew but whose names we cannot now recall. They asked only the chance to try, and we must not forget that their failures are the foundations for the very things which we today regard as necessities for the production of petroleum.

Let us review briefly some of those producing necessities.

Depth and Pressure Increases

For wells drilled to greater and greater depth and into higher and higher pressures, there is the continuous improvement in alloys and heat-treating for casing and tubing and in their threads, the API round form and a long list of special purpose threads.

One of the most recent production equipment developments is the so-called permanent completion equipment which should allow decreased workover costs.

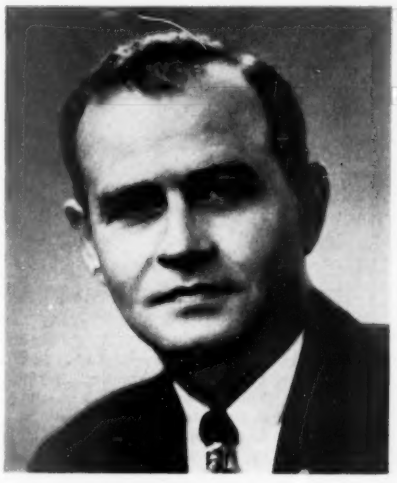
Packers have undergone a most astounding development. From the simple shirt tail and tool-set line packers, the development has taken so many different directions that a Rip Van Winkle, waking just in time to hear a conversation between men talking about packers, would, from the multiplicity of terms, believe he had discovered the tower of Babel.

In the 20 years, equipment for well control and the handling of produced fluids has undergone great changes. The problem has been greatly complicated by high formation pressures and a multiplicity of casing strings, most particularly the rather universal, new practice of flowing production through tubing.

Elaborate equipment has been developed for surface pressures as great as 10,000 psi. Many novel sealing devices have been incorporated into valves. Automatic controls have been applied to both flowing and pumping wells. Timing devices start either flowing or pumped production at a preselected time and shut it in according to schedule. Emergency shut-off valves, either in the well or on the surface, guard against the breakage of a flow line or damage to the wellhead itself.

To make the pumper's job easier and allow his time to be spent on more productive work, lease tanks are now switched

The Author



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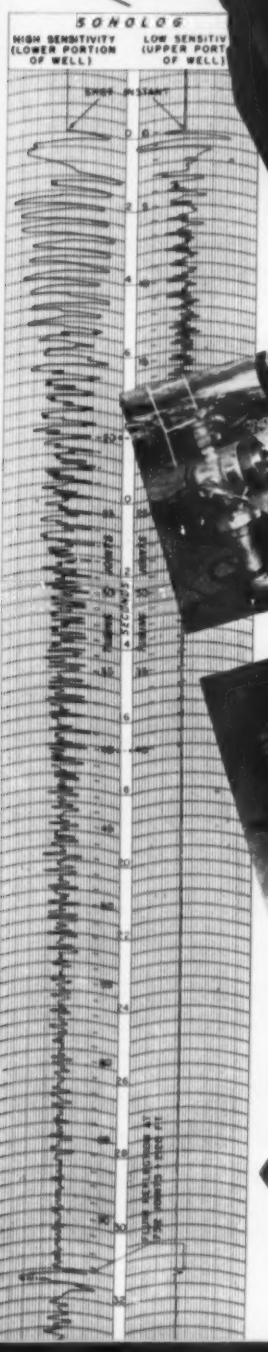

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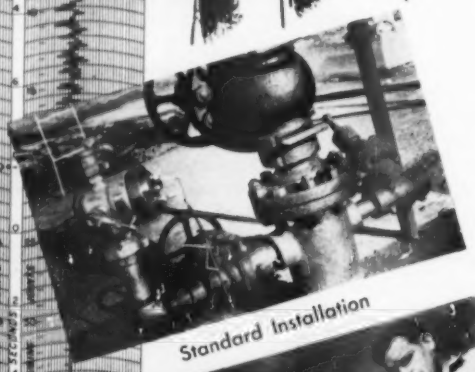

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Typical log obtained from one shot and accompanying echoes down well. Two sensitivities permit amplification of impulses as they become dampened farther down well, enabling fluid level to be accurately determined.

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Handling Well Fluids

The discovery of many gas condensate reservoirs has added greatly to the problem of handling well fluids. Freezing as a result of reducing high pressures at the surface has made it necessary to heat well fluids as they come from many of these reservoirs. The problem of safe, effective heating has sought many solutions. The application of heat indirectly through a hot water bath with immersed well fluid coils appears to satisfy conditions the best at this time. Another approach to handling high pressure gas condensate production at lowered temperatures is removal of water vapor in the gas phase to prevent its freezing to form hydrates. Both pelletized solid and liquid water vapor absorbers, capable of regeneration, are used.

Another solution to the dehydration problem is the use of what is known as low temperature separation. The low temperature separator takes actual advantage of temperature reduction from gas expansion to condense water vapor and the heavier hydrocarbons. Low temperature separators in some instances are able to remove such large percentages of the liquefiable hydrocarbons that gasoline plants to strip the remainder of these hydrocarbons from the gas are not economical.

Installation and upkeep of oil field tankage has always been costly. To serve the purpose of tanks used solely for engineering and control volume measurements, fluid meters have been developed — largely adaptations from other uses — capable of providing measurements adequate for the needs at costs lower than measurement in tanks.

During the past 20 years, managements of production operations have come to rely heavily upon reservoir performance predictions. To meet the requirement for basic reservoir data, wire line instruments for measuring pressure and temperature, for sampling reservoir fluids, and for securing other data, have become widely available.

A battery of pumping units and workover rigs lines a portion of the California Coast production from under the Coastal Shelf.

Subsurface Equipment

In production operations the increasing costs of servicing subsurface equipment have given impetus to numerous items of equipment which, like subsurface pressure and temperature instruments, can be run on a wire line. This numerous family of cost-saving tools includes, to mention only a few: chokes, regulators, perforating equipment, permanent completion equipment previously mentioned, and gas lift valves, which will be discussed later.

The costs of well servicing have been considerably improved by the development of self-propelled high capacity telescoping derricks and masts mounted with production hoists. In some areas these units eliminate the cost of installing many production derricks. The surface work of well servicing has been expedited and made more safe by the use of air-actuated tools, such as slips, tubing tongs and rod wrenches which also eliminate much human fatigue and consequent error.

During the 20 years artificial lift equipment has passed through innumerable development phases. Subsurface hydraulic pumping has proved economical in numerous locations, particularly since the development of a subsurface unit which eliminates servicing equipment by being carried into and out of the hole by the fluid stream used to actuate it.

Gas lift appeared obsolete as a production method when wide-open and wasteful production of wells was curbed. But the introduction of gas lift valves in innumerable forms and with countless auxiliary and modifying items has so reduced the gas volumes and pressures required for operation that gas lift has become a process which must not be overlooked in any artificial lift situation. Under development, and adding to the attractiveness of gas lift equipment, are valve mechanisms which are wire-line installed and serviced. Nowhere in the oil field equipment industry has competition been so keen as in the development and sale of gas lift equipment — and nowhere in the oil field equipment industry have such great improvements been made.

Artificial Lift Equipment

Sucker rod pumping, perhaps, remains the predominant method of artificial lift in the industry, but it is hard-pressed to extend itself economically to the full range of conditions which must be met. During the past two decades the unit pumper, mounting the speed reducer and pumper structurals, has come into almost universal use, replacing individually set components. The size of some of these units used today would have been considered unrealistic 20 years ago. Indeed, the fantastic quantities of cast iron and steel now required in surface and subsurface equipment to pump nominal volumes from depths common today present the greatest single challenge existing for inventors, designers, manufacturers, and users of production equipment.

One of the attempts to meet that challenge is in the evolution of the long stroke hydraulic pumper. To date, it has served the purpose of extending the depth to which sucker rods may be used — at the cost of efficiency, however, for it involves two hydraulic mechanisms, neither of which can approach the efficiency of modern speed reducers and belt drives.

Subsurface pump manufacturers have participated in the fight against costs by using hard and noncorrosive metals, but their most effective development during the 20 years is

An ancient pumping unit still functions at a Central Texas location.

the rod-type pump which can be replaced without an expensive tubing pulling job.

Increasing numbers of multiple-zone completions because of lowered drilling costs have created a demand for lifting equipment to handle more than one producing zone in a well. Ingenious installations of gas lift equipment have been more successful as a whole than have been installations to pump more than one zone. Dual zone pumps are in the incipient stage of development and the success of manufacturers in evolving satisfactory equipment may have considerable effect on the future sales of all pumping equipment.

Fight Against Corrosion

Efforts to reduce production costs caused by corrosion have gradually increased during the 20-year period until at present the greatest concerted attack on corrosion in industry history is being made. Cathodic protection of several types has become common. The use of organic inhibitors, particularly to protect subsurface equipment in wells, has had outstanding success. Flow line insulators are being used in many areas to cut stray "battery currents" off well equipment. It is believed that much cost will be eliminated, particularly in the repair of oil casing strings and in the loss of oil and gas through casing leaks.

The fight against costs and to secure better operating conditions has extended aggressively to the disposal of salt water, to secondary recovery operations, to formation stimulation techniques, and to gas conservation. In these operations equipment problems have been solved largely by the redesigning and adaptation of existing equipment to new functions and to the necessity for cost reduction.

Exemplifying such metamorphosed equipment is the direct-connected gas-engine-driven compressor. In 20 years, it has been redesigned to minimize horizontal reciprocating forces and it has been mounted on typical oil field skids with all accessories, including its own cooling system. It can now be set or moved with greater economy and its operation cost in many instances is greatly reduced because it is reliable enough for operation by the lease pumper as a part of his routine duties.

To the preceding brief recital of achievements in the development of petroleum production equipment, every user of such equipment will no doubt wish to add something. We might, indeed, become complacent with achievements in which every individual connected with petroleum production may take some credit.

Economics of Demand

But, we canont afford to lose sight of the fact that this host of material advances has come about solely because more and more people wanted to use petroleum products. More people have wished to drive automobiles. More people have wished to travel by plane. More and more users of petroleum products have been attracted by the economies of diesel engine operation. And manufacturers wish to use more petroleum fuels because they have learned of their economy and clean burning. Millions of people have become conscious of the convenience and cleanliness of petroleum for heating their homes.

And we cannot afford to forget that all these new users were attracted because petroleum products could be made available to them at a cost they were able and willing to pay.

Product cost control is undoubtedly the key to the future of the petroleum industry. And the cost of finding and producing petroleum is a dominant factor in the ultimate cost to consumers. In finding and producing petroleum, inflation has laid a damaging hand on the costs of necessary equipment and services; and so, from inflation alone, the cost of producing petroleum has risen with the price load in the United States. But more serious than general inflation are the increased costs from the facts that wells are deeper; they are in swamps, deserts, or the ocean. They are beset by corrosion or a host of other cost-multiplying conditions.

The load upon the men who produce production equipment — from an idea to universal field acceptance — is to be heavier in the future. These men must give the petroluem industry equipment which will allow that industry to supply its products to people who want them, at the prices they can and are willing to pay. They must do this regardless of the fact that producing conditions will become constantly more difficult.

That the men who must develop future petroleum production equipment may carry an increasingly heavier load, the least any of us can do is our part to see that these men and all other Americans retain their right to work as hard as they wish and exchange the products of their efforts, if and when they please, for products of others who are similarly free to work and exchange the products of their labor.

A worker thaws connecting pipes of a separator to clear the ice during winter operations at an Imperial Oil Co. producing well at Joseph Lake.

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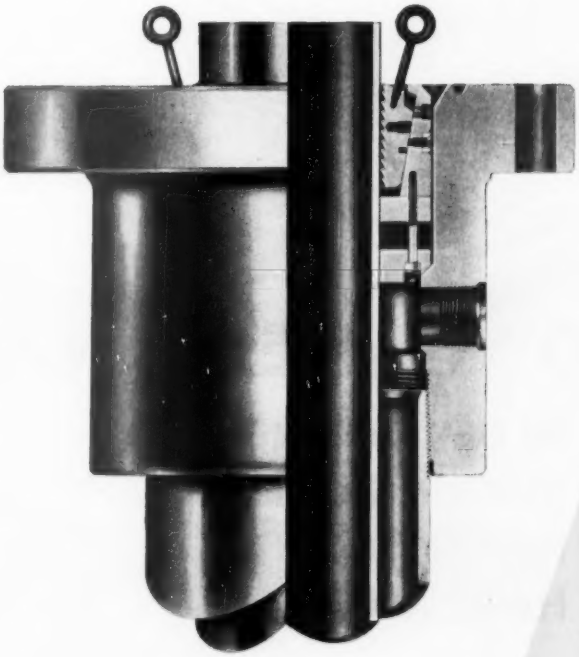

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Some Features of Growth In Fluid Injection Techniques

By

William L. Horner

Vice President, Sunray Oil Corp.

and

Albert E. Sweeney, Jr.

Director Secondary Recovery Div., Interstate Oil Compact Commission

Members AIME

One of the most interesting and creative segments of oil production is in fluid injection. Pressure regulation[1] and water flooding by fluid injection have for two decades been increasing in importance, both to the oil producer and to the technologist. Approximately 20 per cent of the U. S. oil production is furnished by fields which receive fluid injection, including pressure regulation and water flooding. With the application of fluid injection becoming greater year by year, and with the increased amount of technical information on hand, it should be desirable to review some of the highlights, both as to application and as to technology.

The history of fluid injection in the United States indicates that the practice originated in Pennsylvania. Torrey[2] credits J. D. Dinsmore with the first gas injection project, in Venango County, Pennsylvania, in 1888. The first water injection projects were in the Bolivar and Richburg Fields, New York, about 1912. Pressure regulation by gas injection began at Sugarland Field, Texas, in 1930, and credit for the first water injection pressure regulation by salt water disposal in the producing sand, goes to the East Texas Feld in 1938. The Midway Smackover Limestone Field in Arkansas, has been named by some as the first (1943) in which water is injected expressly for field-wide pressure regulation in a new pool.

The revolutionary influence of technology is revealed, in that predictions of recovery made two decades ago depended almost entirely upon individual pilot tests. In contrast, current projects are based entirely upon predictions calculated by engineers, and now usually without any dependence being required on pilot or trial injection. The final calculations, usually simple and straight-forward, are based upon a very complex scientific background, including practically all of reservoir engineering, and also drawing much upon production research and the other branches of production engineering with the use of geology, physics, economics, finally before the practical solution is developed. Expenditures toward obtaining the necessary data and making the necessary engineering and research studies are proved good business, it usually being impossible to obtain comparable results at competitive costs through the use and interpretation of pilot projects.

The growth of the application of fluid injection to oil recovery in the United States is charted in Fig. 1, together with the average price received for Mid-Continent crude. This graph shows large increase in production from fields receiving injection for the period 1932 to 1952 — from 45 to 390 million bbls, or about six per cent of the annual production in 1932. (785,000,000 bbls) to 19.5 per cent in 1952 (2,019,000,000 bbls). Thus the increase in annual production from fluid injection projects is equivalent to approximately 28 per cent of the total increase in annual production.

The relative amount of the total production in each state which came from fields with fluid injection projects in 1952 is shown in Fig. 2. The percentage of the total production from fluid injection projects of each of these states has increased materially since 1932, with the exception of Illinois, where much of the production in 1932 was from shallow stripper fields then using gas injection.

The growth of water injection projects in the United States is shown in Fig. 3. This graph includes all production from projects under water flood and from fields in which the injection is principally water. Since 1932 the production from such projects has increased from 12 million to 236 million bbls annually.

A significant factor in the growth of water injection projects has been in the application to limestone reservoirs. Although artificial water drives (floods) were first applied in the sandstone fields of Pennsylvania and New York, the effectiveness of natural water drive has been appreciated in limestone reservoirs throughout the world. Water injection into a major limestone reservoir in Texas was initiated over 20 years ago in the Edwards Lime pools near Luling, Texas. Although the project was for disposal of salt water, the aquifer has been able to sustain water drive to this date with high water-oil ratios.

An important contribution to the engineering analysis of

The Authors

William L. Horner

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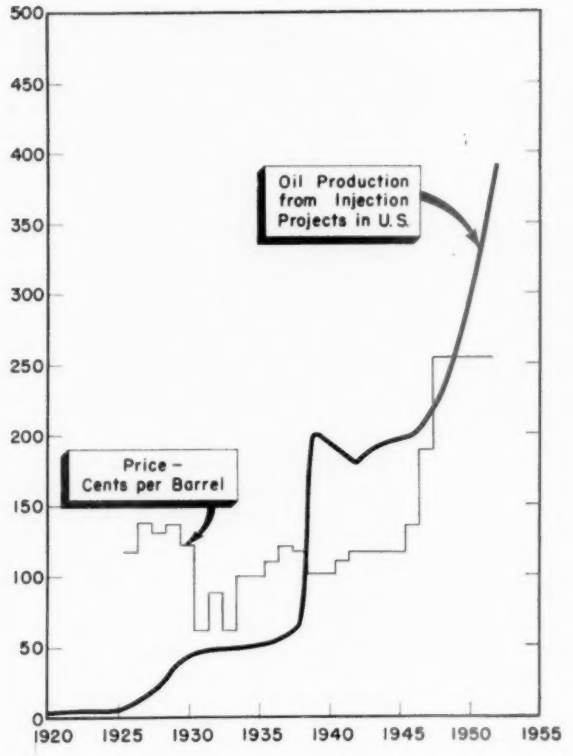

Fig. 1 — Average price Mid-continent crude oil (cents per bbl) and annual oil production (millions of bbl) from fields with fluid injection projects in the United States.

limestone reservoirs was presented by Rupert Craze in 1950[3]. In his paper, Craze pointed out that although some 60 per cent of production comes from carbonate reservoirs, research and study in the development of reservoir behavior has dealt principally with flow of oil through sandstones. Craze found that "the distribution and movement of fluids in and through porous limestones follow the same fundamental principles underlying such process in sandstones." During the period prior to the Craze paper, while favorable performance data on limestone reservoirs were being obtained, numerous theories by others had been successively advanced and disproved as to why pressure regulation might not work in limestone reservoirs. Theories included opposite views, some proposing that water could not be driven into limestone formations, others that channels would cause erratic fluid movement through the reservoir, and another that the pores containing oil were somewhat bottle shaped and contained only one small opening which would impede displacement. The availability of improved scientific methods for the study of limestone reservoirs and the accumulation of favorable case histories of fluid displacement in limestone reservoirs has aided in the productive expansion of such projects. Records of the Interstate Oil Compact Commission[4] show that in 1952 there were approximately 40 water injection projects in limestone reservoirs in the United States, and numerous additional projects are underway at this time in most limestone producing areas of North America.

The growth of gas injection projects in the United States is shown graphically in Fig. 4. This graph shows the annual production from gas injection projects (exclusive of cycling). Since 1932 the annual production from such projects has increased from 23 to 160 million barrels annually. The data charted in Fig. 5 shows the results of an important trend from gas injection toward more water injection. Projects under gas drive have been converted to water flooding as this method proved its superiority in many fields. In a recent article, P. E. Fletcher[5] located 25 gas injection projects in West Texas. Seventeen of the 25 gas injection projects are now converted to water floods or are in various stages of being converted to water injection projects. A recently announced major project[6] is in the 14,000-acre south dome Unit of the Goldsmith Field. At the unitization hearing, which resulted in Commission approval, Gulf Oil Corp. explained its pressure regulation program as being essentially water displacement supplemented by injection of residue gas for the purpose of assisting toward holding the gas-oil contact. Gravity drainage from the gas cap is not anticipated by such a program designed mainly for water drive. Also, in other states the growth of water injection projects has been favored by numerous cases wherein crestal gas injection has been supplemented and later supplanted by water injection. Significant examples of major gas injection projects being converted toward water injection are widespread, and include North Burbank in Oklahoma, Louden in Illinois, Lance Creek in Wyoming, Haynesville in Louisiana, Schuler in Arkansas, and Poza Rica in Mexico. The case histories of such projects should not be overlooked by engineers.

An appropriate current example of the growth of pressure regulation and secondary recovery engineering techniques is available in the SACROC Unit, which embraces the Kelly-Snyder Field, Scurry County, Texas. Unitization agreements were approved by the Railroad Commission of Texas on January 30, 1953, making the Unit effective as of March 1, 1953. The Unit has designed a program, and will commence injection after receiving approval from the Railroad Commission of SACROC's injection plan (Fig. 6) and proposed field rules.

The field is outstanding, not only for its size (approximately 49,000 acres in area, over 11,000,000 acre ft in reservoir volume and 1,239 oil wells), but also for the unparalleled amounts of engineering and research data utilized, and for the thorough engineering studies which it has received. A fair coverage of current technology is provided by this example. During the drilling of this field, data were obtained from every well. Logs were run on each well, either electrical or radioactive, or both types of logs. One hundred and five wells were diamond cored. Approximately 10,000 core samples were

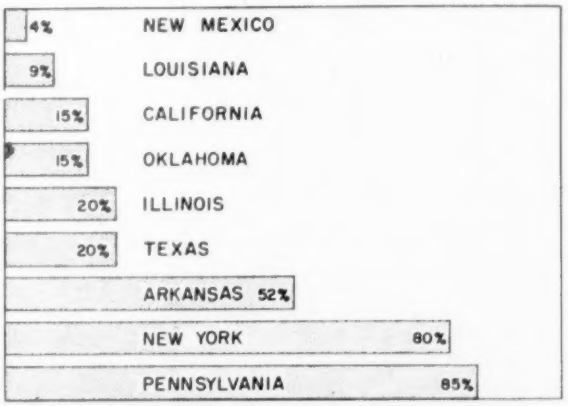

Fig. 2 — Importance of fluid injection by states. Per cent of 1952 oil production obtained from fields with fluid injection projects.

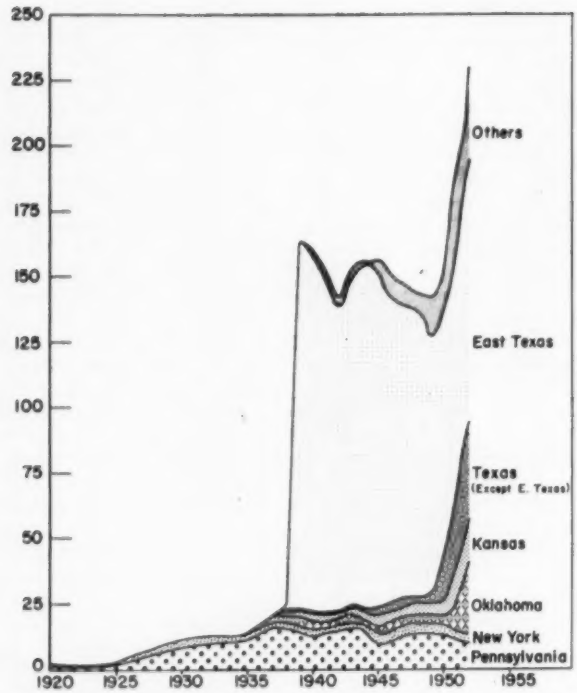

Fig. 3 — Growth of production from fields with water injection projects in the United States. Annual oil production in millions of bbl (includes both water flood and pressure maintenance.)

tested to determine the amounts of residual oil and water, permeability and porosity, and other physical properties. Special tests to determine interstitial or connate water contents were made on approximately 1,700 samples. The connate water determinations were compared with tests on samples from three wells cored with oil. Over 50 core samples were tested to determine the percentage of oil recovery obtainable by water flooding. Consistent results were obtained by various laboratories and different methods for determining recovery from core samples. On 14 samples, SACROC found water-drive recoveries of 51.27 per cent oil recovered. Similar samples yielded 58.7 per cent oil recovery by following the procedure prescribed in a recent publication of Rapoport and Leas[7] of Carter Oil Co.

Mobility ratio[8,9] is recognized as a valuable and measurable factor which is related directly to the degree of water production *vs* depletion. The variation of mobility ratio (water to oil) is found to be in the direction of water cut percentage, that is, higher values being less favorable. The mobility ratio for SACROC is one of the lowest measured, being in the order of 3/10. This compares with 9/10 for a measurement of the East Texas Field with less favorable values, from 2.0 to 25.0, estimated for a group of typical water floods.

As a result of eight field-wide surveys of bottom hole pressures ordered by the Railroad Commission, the pressure history is documented by some 4,000 tests on flowing wells. A number of wells were purposely reworked to permit successful pressure tests to be made of various levels in the formation, which averages approximately 236 ft in thickness. The reservoir pressure had dropped from its original 3,122 psig to approximately 1,600 psig after the production of some 97,000,000 bbls of oil, or only 3.4 per cent of the oil in place.

An estimated 2,000,000,000 bbls of oil will remain uncovered after primary depletion. To investigate means to prevent waste and to increase recoveries, additional studies were made after the wells were put on production. More than 20 samples of reservoir fluid were obtained and analyzed. One hundred and ninety-one flowing bottom hole pressure tests were made to determine productivity values for representative wells, and more than 40 wells were tested to determine the rates of pressure build-up. The initial potential and build-up tests gave conclusive information as to the favorable uniformity of permeability within the reservoir, and its suitability for water injection. The data showed absence of any system of fractures or streaks of excessive permeability.

Data for calculating recovery by various methods were obtained from fifteen core samples tested for relative permeability with various fluid combinations. Calculations of the application of high pressure gas injection required extensive laboratory work, which was done on both small and large core samples. Recovery of oil by gas displacement was compared directly to that obtained by water injection.

Research and engineering studies costing several hundreds of thousands of dollars, and all directed toward understanding and improving the recovery from this reservoir, were carried to conclusion by teams of geologists and engineers employed by the operators and by institutions. Besides many private production research laboratories, U. S. Geological Survey, University of Texas, M.I.T., Princeton, and most extensively, the U. S. Bureau of Mines, worked on various phases of this problem. With such complete data available, SACROC engineers were able to employ all of the known methods for estimating recovery by all known procedures of fluid injection. As a result, line drive (Fig. 6) water injection is recommended by the Unit. This pattern was analyzed with the aid of potentiometric model studies. The injection will drive toward the

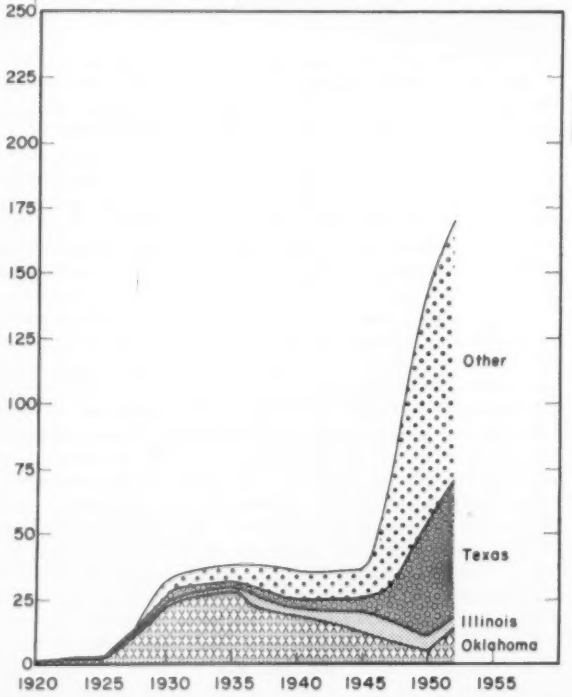

Fig. 4 — Growth of production from fields with gas injection projects in the United States. Annual oil production in millions of bbl.

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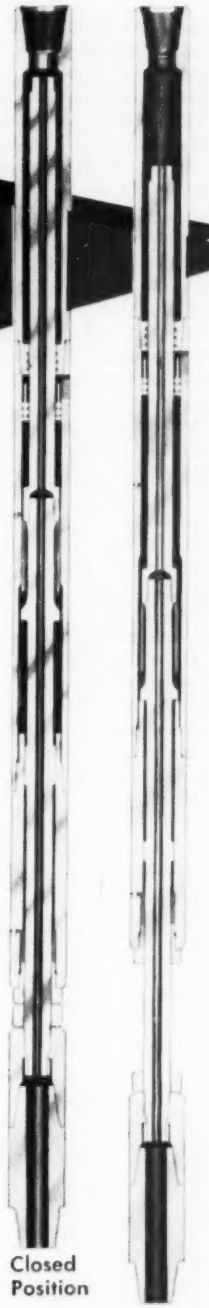

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thin edges, confirming general practice proved in water flooding and cycling projects.

Offered in the foregoing are some of the highlights as to the present stage of production and technology of fluid injection. The literature of secondary recovery indicates that operators have known for several decades that the movement of water or gas through reservoirs would displace oil and that recovery could be increased by injecting water or gas into some reservoirs. Fig. 1 reveals, however, that fluid injection was practiced to only a limited degree before two decades ago, and exceptional growth has been obtained recently. The price history curve on the same chart reveals that the growth of fluid injection accompanies crude price rises. The increase in application due to price rise was anticipated by an engineering commitee of I.P.A.A., which in 1943 calculated that stripper well reserves would be increased 4.3 billion bbls, mostly by water flooding, if the price for crude oil would be increased 50 cents per bbl. In addition to the obvious relation to price, the growth of fluid injection has depended on technology. An example of the parallel development in technology is revealed by the growth in literature pertaining to fluid injection. The *Oil and Gas Journal* in 1932 carried four articles on fluid injection, and 70 in 1952. The AIME *Transactions* contained no articles on the subject in 1932, and eight in 1952. Meanwhile similar growth is found in the literature of other trade journals and organizations.

The universally intelligent administration of state regulatory authorities has been one of the most important factors contributing to the growth of fluid injection as a conservation measure[1,10]. The rapid growth of fluid injection is likely to continue and will be influenced to a large extent by the aforementioned factors. But, in addition, new methods are under development and newly developed methods are being applied[2].

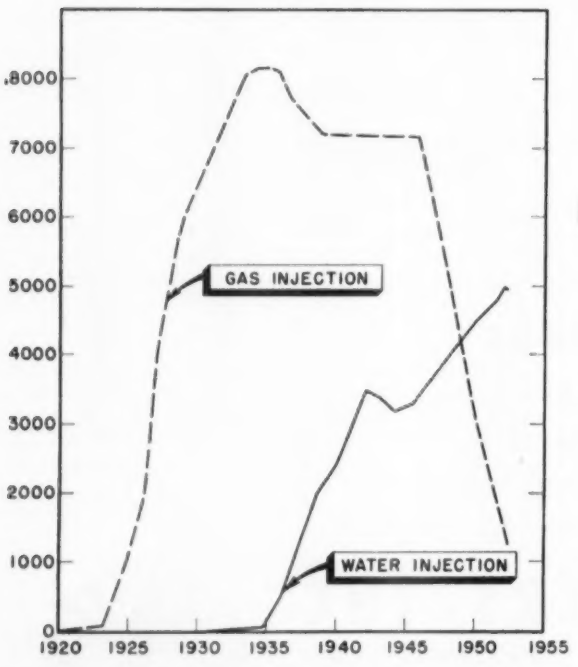

Fig. 5 — Number of producing oil wells in Oklahoma fluid injection projects.

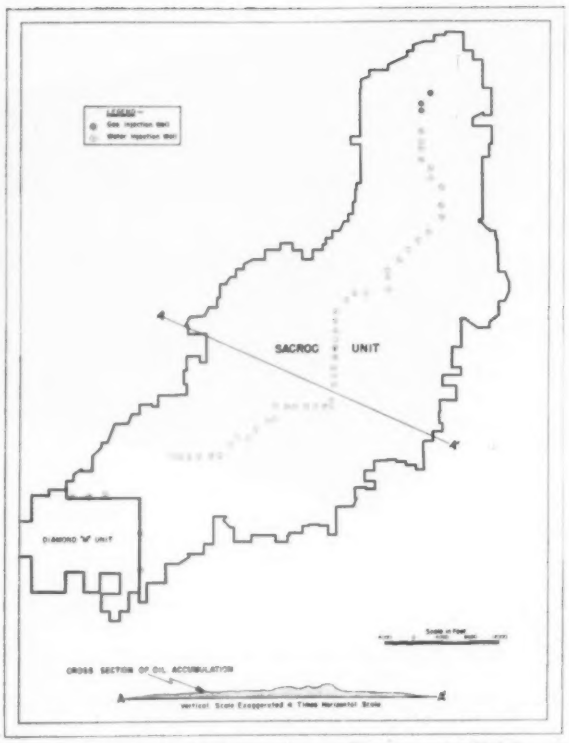

Fig. 6 —Proposed initial injection well array, SACROC unit area, Scurry County, Texas.

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    (b) Arkansas Oil and Gas Commission, "Summary of Secondary Recovery Projects."
    (c) Louisiana Department of Conservation, "Summary of Secondary Recovery Projects."
    (d) Oklahoma Corporation Commission, "Summary of Secondary Recovery Projects."
    (e) Kansas Corporation Commission, "Summary of Secondary Recovery Porjects."

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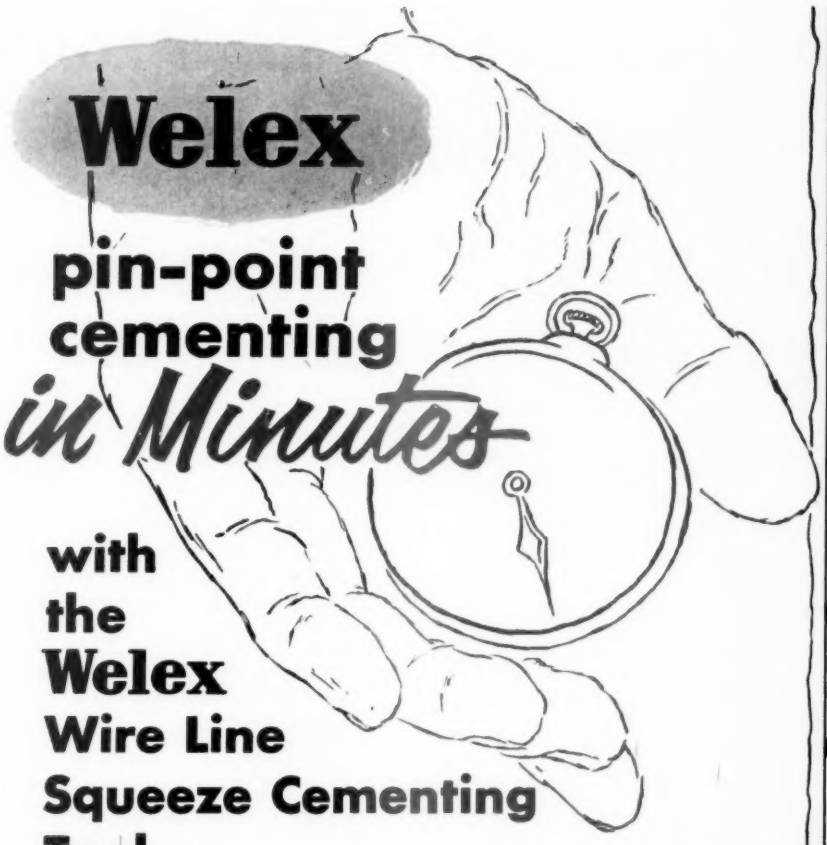

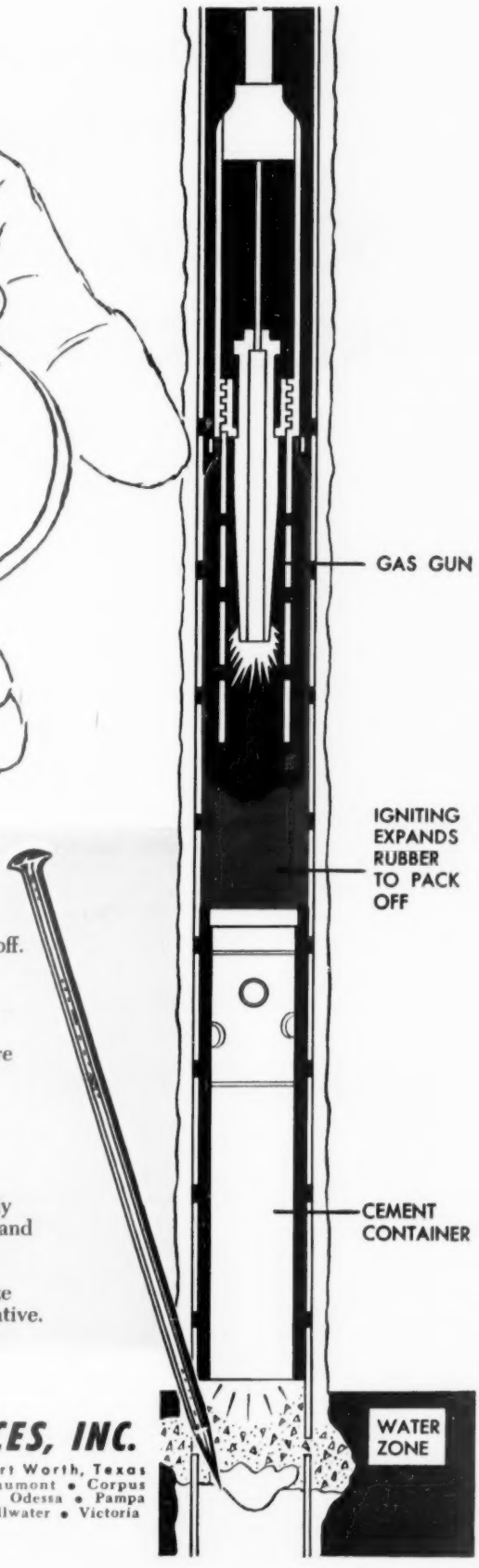

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Milestones in Two Decades of Reservoir Engineering

By

Lloyd E. Elkins
Director Production Research
and
S. J. Pirson
Special Research Associate
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When one is requested to review two decades of development along reservoir engineering lines, the task at first might seem light. In some respects it is not too difficult, but it is extremely hard to survey a period and be absolutely sure that every milestone is properly recognized. The authors realize that numerous contributions have been made which have indirectly served as a foundation to the highlights of development here reported on. Yet, with editorial limitations, we are forced to look only at what, in our opinion, have been the more basic developments.

In the last years of the great economic depression, the term "Reservoir Engineering" had not yet been coined; perhaps it is safer to say that reservoir engineering did not even exist. To be sure, the year 1933 opened with the realization that certain useful reservoir rock and fluid properties could be measured. Fancher, Lewis and Barnes[1] were about to publish their momentous paper and the Darcy unit of permeability was about to be defined.[2] For water flooding purposes, measurements of porosity, permeability and fluid saturation were common indeed in the Bradford oil region of Pennsylvania and New York. In the flush production fields, the almighty "rule of capture" was being placed in serious jeopardy with the advent of "proration" which was necessitated by the serious economic conditions and physical waste within the industry. The production behavior of certain fields was baffling to the industry, such as obtained at Kettleman Hills, California, which could be classified neither as a gas field nor as an oil field. In the early 1930's, it was known, however, that fields could be produced by water encroachment or by solution gas. The effect of a gas cap on recovery was not recognized; in fact, it was customary to blow it off in the expectation that oil might migrate upward into it under the possible action of a water drive. The year 1933 dawned, therefore, with a great many misconceptions and little quantitative information on oil field production.

In the last two decades, simultaneous advances in reservoir technology were made on three basic fronts: petrophysics (the study of physical properties of rocks and their relationship to the contained fluids), physics of reservoir fluids, and basic reservoir performance equations. Concurrent with these fundamental developments, the so-called reservoir engineer has gradually compared field performance with widening theoretical concepts and, fortified with a growing confidence, has launched out to control and/or alter forces to achieve a more perfect degree of oil and gas conservation.

Petrophysics

The measurement of physical properties of rocks received its impetus in the early part of the period with the publication of the paper by Fancher, Lewis and Barnes,[1] already mentioned previously, and soon thereafter in 1935, the "Standard Procedure for Determining Permeability of Porous Media" was adopted as API Code No. 27 by the Topical Committee on Production Technology of the American Petroleum Institute. It was soon realized that if the permeability measurements were to be useful to the production of oil, information on the simultaneous flow of multiple fluid phases should be obtained. The first to publish information of this type was Hassler.[3] The term "relative permeability" was not coined as yet and Hassler's work included only the fluid flow characteristics of the gas phase as a function of oil saturation in consolidated rocks. The first complete relative permeability studies were made on unconsolidated sands by Wyckoff and Botset[4] in 1936. Here complete relative permeability curves were obtained[1] for both the liquid and gaseous phases and for packings of various degress of coarseness using various sizes of sand grains through a permeability range from 17.8 to 262 darcys. It was also shown that relative permeability to oil was an invariant over a wide range of oil viscosities (0.9-3.4 cps). Shortly thereafter, Leverett and Lewis[5] published their results on three-phase flow; this still being the only available information on the matter, although the problem of measuring relative permeability with one phase fixed and two phases moving is of common occurrence at this writing. At about the same time, the universal association of formation

The Authors

L. E. Elkins

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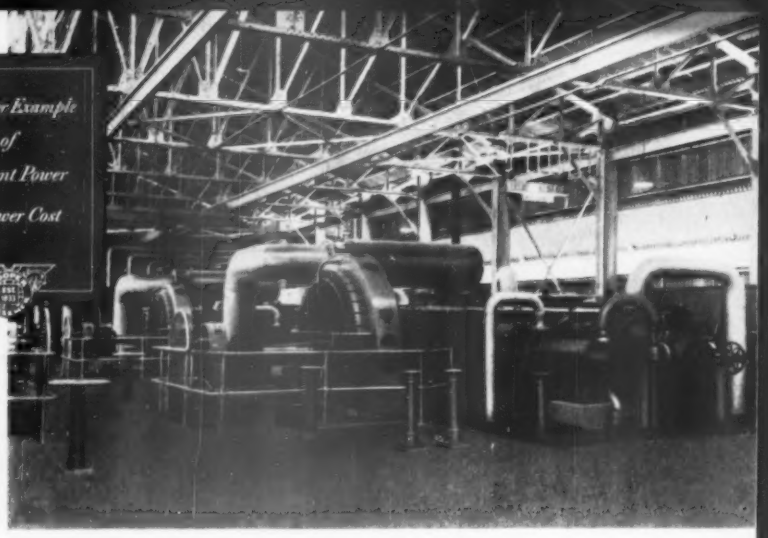

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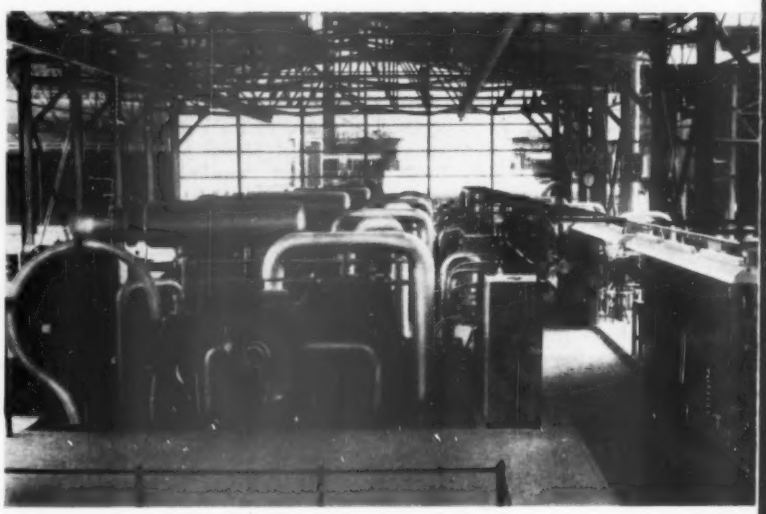

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water with oil and/or gas accumulations was demonstrated by Schilthuis.[6] The results of the research work cited thus far dispelled the misconception which previously existed and proved that oil reservoir rockse are almost never fully saturated with a single fluid under virgin conditions.

These discoveries of the physical properties of rocks, and the dependence of the flow ability of the various fluids upon their corresponding degree of saturation in the pore space, are now considered as the determining conditions of the reservoir fluid mixture composition which issues from a reservoir rock. It explained why the mere presence of one of the fluids, such as oil, does not necessarily indicate oil productivity. This discovery necessarily reduced greatly the importance of oil stains and shows in drill cuttings as indices of the discovery of an economically producible oil horizon, notwithstanding the limitation of productivity which also attends low permeability.

The concept of the intermingling of the fluid phases took on added importance with the introduction of capillary pressure measurements by Hassler[7] in 1943. While the effect of surface forces on the production of oil and water had been foreseen for many years, a practical way of gaging them was not available until the measurement of the capillary forces between the various fluid phases in a porous rock could be related to the corresponding pore space saturation. The oil industry had been slow in assimilating the conclusions reached already many years before by hydrologists and soil scientists, but it dispelled readily the misconception of a definite oil-water contact in most oil fields unless their specific rock permeability be extremely high. In most cases the concept of an oil-water transition zone or gradually changing fluid saturation in the respective phases had to be introduced. In the field, the new views were responsible for better well completions; in the laboratory, many flow tests designed to study the recovery under artificial drive (water or gas) had to be discarded and redesigned in order to eliminate the end effect caused by capillary action.

Last, but not least, of the important developments of the last two decades in the petrophysics phase of reservoir engineering was the realization of Archie[8] that there is a relationship between the resistivity of a reservoir rock as measured by electric logging of wells and the degree of formation water saturation; therefore, also with the productivity of a well. This discovery virtually touched off a chain reaction in the realization that electric logs which originally had been introduced as a geological tool actually contained a wealth of quantitative reservoir data hitherto unexplored. The developments were rapid and presently we are able to determine the following information from adequate combination of well logs: porosity, water saturation, order of magnitude of permeability and net pay. In addition, distinct possibilties exist for determining productivity in terms of expected water-oil ratio and probable producible reserves.

Physics of Reservoir Fluids

It is presently common knowledge that the phase condition in which petroleum hydrocarbons may be found in a natural reservoir when first discovered fall into three classes:

1. Single liquid phase, all the available gas being in solution in the reservoir oil at its bubble point or at a higher pressure in the case of an undersaturated reservoir.

2. Two-phase system composed of an oil column and an original gas cap, the oil being at its bubble point pressure.

3. Single vapor phase, which comprises fluid at a pressure and temperature higher than those defining the critical state for the mixture. These reservoirs are presently referred to as "condensate" or "distillate" fields.

The first two classes of fields were well known in 1933 and Comins[9] had described in a masterly manner their relationship to geological conditions before the First World Petroleum Congress in London during that very year. However, Kettleman Hills production did not conform in any way to the first two classes of fields. It had not been customary in physical chemistry courses of the first three decades of the 20th Century to study the phase behavior of mixtures, and the work of J. P. Kuenen and H. W. B. Roozeboom on heterogeneous equilibria was all but forgotten. Credit to revive the interest in the matter and to apply it to hydrocarbon mixtures is due to Sage, Lacey and Schaafsma.[10] Their paper marks the turning point in the realization that a third important class of field exists. From then on, it was but a short time before the full explanation of the behavior of Kettleman Hills was understood[11]. With deeper drilling, many condensate fields were discovered along the coast of Texas; this created a temporary problem of distillate crude production with extremely high gas-oil ratios until the practice of cycling was developed which permits a high degree of recovery and sweep efficiency.

Throughout this 20-year period, bottom-hole pressure measuring instruments and fluid sampling devices saw a high degree of development under the encouragement of the U. S. Bureau of Mines and of the research departments of various oil companies. It became possible to measure bottom-hole pressure with a degree of reliability of plus or minus one per cent and to determine with a high degree of precision reservoir volume factor, gas in solution, oil and gas viscosities and compressibilities. These constitute the basic information needed for reservoir performance forecast for which methods were soon to be developed.

Basic Reservoir Equations

The tools of the re-ervoir engineer have definitely become mathematical in nature and presently any reservoir analysis includes two aspects: one requires *an inventory of the fluids* in place from time to time during depletion, and the other *a displacement efficiency calculation* utilizing the type and amount of energy available.

Two methods for making the fluid inventory-time study of a reservoir were presented early and almost simultaneously in the period under review. An approach proposed by Katz[12] consists in a lengthy tabulation of the fluid volumes involved and their changes with time whereas the approach proposed by Schilthuis[13] makes use of a simple equation which includes the same terms but reduced to their simplest expression. It was shown that the two approaches are algebraically equivalent, as they should be, since they are both the statement of the same principle of conservation of mass applied to a closed reservoir entity. Because of its simpler usage, the material balance equation of Schilthuis has superseded in practice the method of Katz. Notwithstanding its limitations, the material balance equation is indeed a most powerful tool in the hands of the reservoir engineer; it provides an ever-present inventory and balance between the fluid volumes originally present, those produced, those remaining in the reservoir, and those which might have migrated into it. As such, it does not inform us as to the actual location of the fluids within the reservoir since, as a statement of the conservation of mass, it cares not as to where the fluids are nor whence they come;

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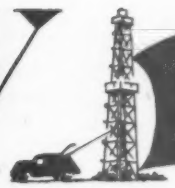

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HERE'S PROOF

(Actual jobs selected from recent McCullough field reports.)

1. New Well—3½", 30-shot McCullough M-3 Burrless Bullet Perforator used to shoot 600 holes between 12,400 feet and 12,500 feet through 5½" O.D. cemented casing. Formation was hard limestone. The well produced 1560 B/D after perforating. Time on the job—six hours.

2. This well was previously perforated by two different companies without results because of an excessively thick cement sheath behind the 7" O.D., 23 lb. casing. Six holes were shot between 6688 feet and 6690 feet with a 4¼" McCullough Glass Jet Perforator and Steel Strip Carrier. The well produced 50 B/D. Time on the job—two hours.

3. New well. 5½" O.D., 17 lb. casing was cemented in 9" hole. Hard limestone formation and an extra thick cement sheath. 3½", 30-shot McCullough M-3 Burrless Bullet Perforator shot 120 holes between 4430 feet and 4460 feet in two hours rig time for production of 100 B/D. A fine well for the field.

4. Formerly perforated for a production of 210 B/D McCullough Glass Jet Perforator and Steel Strip Carrier shot 600 holes below 6000 feet through 7" casing. Time on the job—eleven hours. Production increased to 676 B/D.

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it merely says that they are within the confine of a geologic reservoir entity and presumably under static equilibrium.

Hence, additional information must be secured in order to derive the full measure of the material balance equation. Volumetric factors which are included in the Schilthuis balance are the volume of the original gas cap and the cumulative water influx. The former may be obtained from geological observations, well tests and logging information, whereas the latter is not as readily accessible. The necessity for a determination of the cumulative water encroachment term and of its rate of influx became immediately apparent and Schilthuis himself proposed a method for its evaluation which is still much in use today. Determining the Schilthuis rate of water influx, however, is a matter greatly dependent on the collection of accurate past history production data. Hurst[14] recognized the advisability of determining the rate of water influx independently from the material balance equation and past production data, making it dependent only on rock and fluid properties and pressure history. The method was further expanded at a later date by van Everdingen and Hurst[15] in order to render it applicable not only to reservoirs enclosed by an infinite aquifer but also to those contained in an aquifer of limited extent.

Methods for the calculation of the displacement efficiency of water encroachment or of an expanding gas cap have their origin in a momentous contribution of Buckley and Leverett[16] on the mechanism by which any fluid non-miscible with oil is able to displace oil from a porous rock. In effect, these authors proposed two point equations, one governing the fraction of the displacing fluid flowing with the oil through an infinitesimal rock volume element and the other the rate of advance of a particular degree of saturation in the displacing fluid that exists in that element. It may be said that these equations are all inclusive of the rock and fluid properties as well as of the rate of displacement and the direction of flow. It therefore became possible to gage in a water drive, in a gas drive, or in a gas-cap injection program, the effect of oil viscosity, relative permeability ratio, rate, degree of formation dip, capillary pressure gradient, differential fluid density, etc. That these equations could be reliably used in practical problems is being realized rather slowly by the industry. Some objection is made on the applicability of steady state relative permeability curves and static capillary pressure measurements obtained in the laboratory to the actual transient state. These fears should have been dispelled by a contribution of Terwilliger, Wilsey, Hall, Bridges, and Morse[17] which showed that the transient saturation distribution obtained in gravity drainage could be predicted with great accuracy from steady state relative permeability and static capillary pressure curves. The practical use of the Buckley-Leverett equations in actual reservoir calculations has not yet received the generalization that they deserve, perhaps because of the inaccuracy with which reservoir rock properties are known, owing to the meager sampling provided by core analysis as well as to difficulties in restoring reservoir conditions in the laboratory. A laboratory demonstration of the significance of these fundamental equations was reported by Holmgren and Morse[18] and further elaborated on by Geffen, Parrish, Haynes, and Morse[19] when they specifically studied the significance of a trapped and immovable gas phase in reservoirs where water is the displacing fluid. This pointed to a possible reversal in thinking concerning the importance of maintaining pressure above the bubble point in water drive reservoirs and also suggested an approach for increasing recovery in water flood operations.

A very serious difficulty in water drive, in gravity drainage, and gas-cap expansion, especially when the direction of drive is at right angle to bedding plane and to stratification, is the determination of overall flow characteristics in the vertical direction. The recoveries predicted by frontal drives are inherently too high in such cases when the relative permeabilities are determined from past production data and the results often need an adjustment in order to achieve a satisfactory agreement with material balance calculations.

A very significant paper of recent years in the field of frontal drive recovery calculation is that of Kern[20] where deductions are made which greatly simplify and enhance the significance of frontal drive calculations. In particular, it leads to the calculation of the increased oil recovery obtainable by injecting gas and forcing it into solution in the reservoir oil at a displacement front.

Whorton and Kieschnick,[21] combining the concepts of retrograde vaporization and condensation in a frontal displacement system, conceived a process for high oil recovery efficiency by injecting gas at pressures substantially above the saturation pressure of the oil in the reservoir. This process is being piloted in Block 31 Field in West Texas.

Integration of Fundamental Developments Into Practice

It is really difficult, and unfair to many, to single out individual studies as outstanding in the application of fundamentals in practice. More often than not studies of equally outstanding character remain unpublished in Company files. Even in the technical literature, reports are made which imply that very detailed reservoir engineering studies have been made, but the studies themselves are not reported. Nevertheless, by way of illustration, the authors feel that they must single out specific examples to avoid useless generalization.

In the study of water drive performance, the analysis of the East Texas Field and its performance as related to the Woodbine aquifer is characterisitc of the type of studies that can be and often are made on many water drive reservoirs. Typical of the thorough reservoir engineering studies made on East Texas are those reported by Schilthuis and Hurst,[22] Buckley,[22] Rumble, Spain and Stamm,[24] whereby the pressure history of the field is predicted as a function of time and withdrawal rates, and as related to pressure transients throughout the Woodbine Basin.

It is doubly significant that these studies led first to a most constructive conservation program in the largest known single oil field in the United States and second, while the studies extended over a period of years, they set a pattern for analyzing this type of reservoir.

The Schuler Field in Arkansas is one which has been scrutinized very carefully by Old,[26] Kaveler,[26] Tarner, *et al.*[27] This is an excellent example of a continuous study on a reservoir where gas was first injected to restrict pressure decline and maintain flowing production and create a partial gas cap drive, later to be augmented with an end-to-end water flood while pressures still remained relatively high. While some conclusions were controversial, the facts indicate Schuler will attain a very high recovery efficiency and this because of reservoir engineering work.

One cannot overlook the thorough treatment of primary high pressure water flooding in the Pettit lime at Haynesville, Louisiana, reported by D. W. Akins, Jr.[28] A well-planned program, taking advantage of both gas injection and water injection with 80-acre spacing is another example of good

reservoir engineering planning. It is also illustrative of the type of program that can be worked out with an engineering committee representing the operators involved.

The thorough report of the planning and execution of the gas cycling program in the Bodcaw reservoir at Cotton Valley by Miller and Lents[29] shows what can be done if complete data are collected and thoroughly analyzed.

The recent classical report on reservoir performance in the Spraberry Fields by Lincoln F. Elkins[30] summarizes an exhaustive study of almost every conceivable factor, microscopic and macroscopic, which could influence the recovery mechanism. If the importance of reservoir engineering as a real guide to management was ever seriously questioned, this study should alleviate many doubts.

Many of us in A.I.M.E. may have missed a very excellent study of limestone field reservoir performance relating to southwestern Iran. H. S. Gibson[31] in accepting the British Redwood Medal in 1948, reports how his organization has used fundamental reservoir mechanics in the study of water encroachment and gas segregation in fissured limestone and how displacement efficiency is influenced by producing rates.

The authors again wish to emphasize the importance of literally hundreds of papers not cited in this review. Almost every paper, if not all, which has been published in the Transactions of the Petroleum Branch of A.I.M.E. during the last 20 years supports the advances of petroleum technology and these Transactions more truly describe the real milestones in reservoir engineering.

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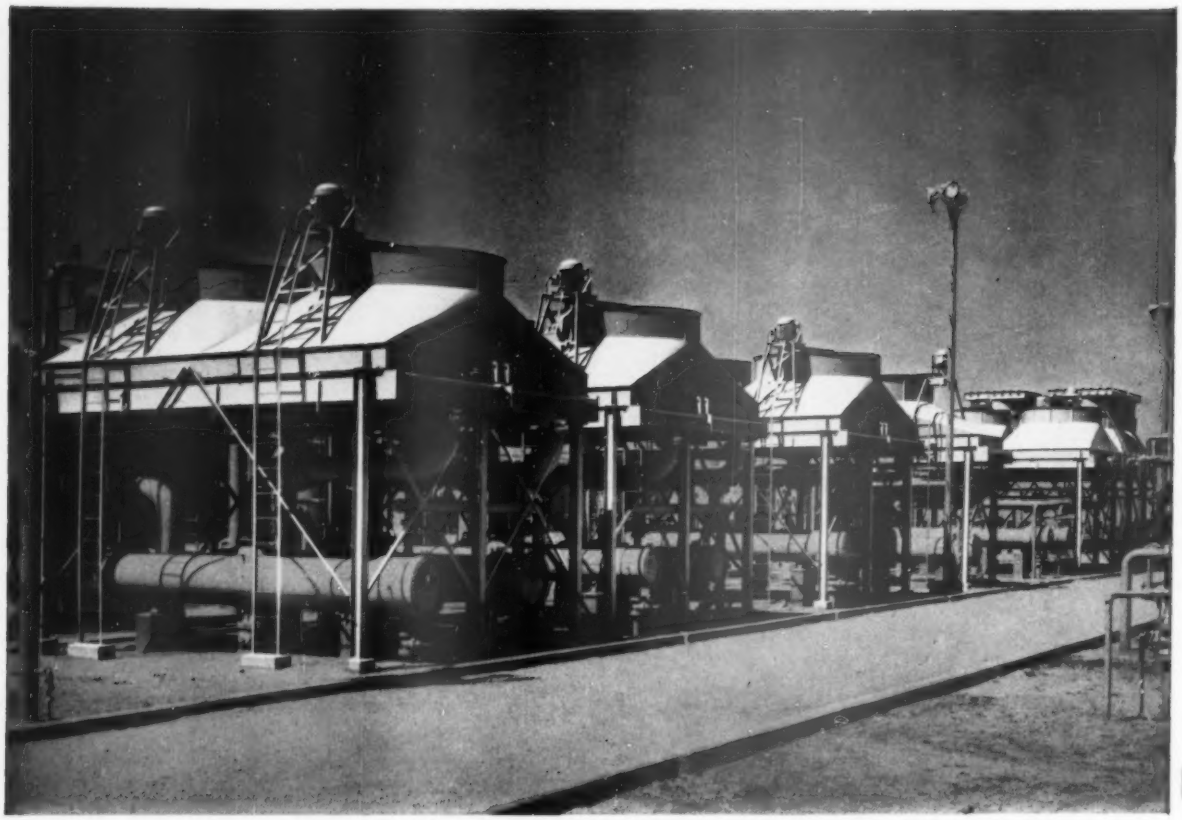
GAS TECHNOLOGY



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Gas Technology— Its Growth and Development

By

Ralph E. Davis

Petroleum and Natural Gas Consultant

Member AIME

It is customary today to consider the natural gas industry as nation-wide in scope. Developments and events in one area are often of interest to gas men and to consumers in other areas, from California to New England and from Louisiana to the Pacific Northwest. This is a relatively recent situation, and in this paper it may be interesting to recall some of the events of the past few decades which influenced the national development.

Prior to about 1925, natural gas service was confined largely to markets located relatively near producing gas and oil fields in parts of the Appalachian region, Oklahoma and Kansas, including the western border of Missouri, to northern Louisiana and parts of Arkansas, to portions of Texas and southern California, and in Canada a part of southern Ontario and several cities and towns in Alberta. The total population of all the areas served was around 12 or 14 million people, and gas consumption, exclusive of field use, was below a trillion cu ft per year. In the past quarter century, gas has been piped longer and longer distances, so that today the nation's major gas provinces are tied to the heavy consuming areas. Accordingly, one important phase of the history of the gas industry is the history of the pipe lines.

The three fundamental requirements for a workable pipe line project, whether the distance contemplated is 200 miles or 2,000 miles, are these: first, a sufficient and suitable gas supply; second, a sufficient and suitable market; and third, a distance between the two which permits the construction and operation of transmission facilities on a financially sound basis. It is not likely that these fundamentals are any better understood today by entrepreneurs seeking to promote 1,500-mile projects than they were understood some 30 years ago in connection with 200-mile projects. There is, however, this difference. A great deal has been learned in the art of studying and estimating gas reserves, their longevity and availability. In this paper, I shall discuss briefly some developments in the estimation of gas reserves, and then consider the history of the financing of long-distance pipe line projects.

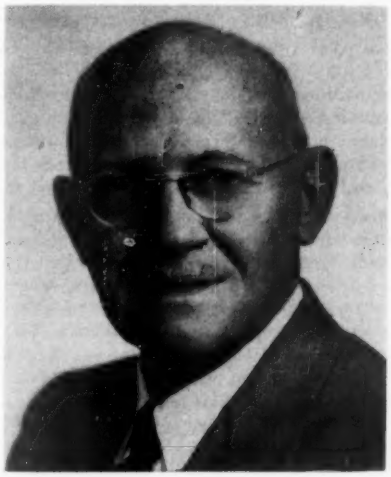
Reserve Studies

In the 1920's when a number of important pipe line projects were carried to completion, we who were active in the study of reserves lacked such information as is now made available by seismic studies and electrical and radio-activity well logging. We had never heard of interstitial water, and frankly, I doubt that any of us ever gave it a thought. We did not have cores and core analyses to enable us to better understand the reservoir rock. Permeability was a term unknown to the art and we judged the practical aspect of the flow of gas through reservoir rock by the open flow capacity of wells. In my studies at that time I took no account of reservoir temperatures, nor did I even consider the greater pressures in the reservoir rock than those recognized and determined as well-head pressures. Generally, future production was largely based upon decline in pressures and rate of production as reflected in the decline curves used in estimating reserves both for gas and for oil wells. Some of the factors which were not recognized or were ignored, would tend to inflate the estimate, others would tend to diminish it. In any case, and for whatever reasons, we did not get into any serious trouble in our reserve estimates. I believe that, to a great degree, that was due to the fact that we were building lines from fields not yet fully developed and proved. Closer estimates can be made today, and in many cases must be made, where we no longer have as wide a margin for error and cannot depend too much on unknown factors playing generally in our favor.

Financing Some Early Projects

Until about 1925, bankers and insurance company investors considered the natural gas industry as an uncertain business and not suitable for the investment of their funds. Accordingly, up until that time, the growth of the industry was financed from sources other than the sale of securities through banking channels.

The Author



It is interesting to note that even as early as 1911 a pipe line built from the Bow Island field some 140 miles to Calgary, Alberta, was in part financed by the sale of securities to the public through banks in London, England. A prospectus of that financing includes the following excerpts which will appear strange to present readers:

"Lloyds Bank Limited, Bank of Scotland, The Canadian Bank of Commerce are authorized to receive on behalf of and as Bankers for the purchasers application for £811,643 ($3,950,000) 5 per cent First Mortgage Debenture Stock. The price of issue is £90 per cent."

So far as I know, the first natural gas pipe line built in the United States to be financed by what I will call public financing was the Houston Gulf Gas Company, whose line was built from Refugio, near Corpus Christi, to Houston in 1926. A prospectus of that financing includes, among others, the following statements:

$5,700,000 Houston Gulf Gas Company. First Mortgage 6½ per cent sinking fund gold bonds with stock purchase privilege dated January 1, 1926. Due January 1, 1931."

At that time, a natural gas pipe line venture had to show an expectancy of at least an annual return of 10 per cent to attract public financing.

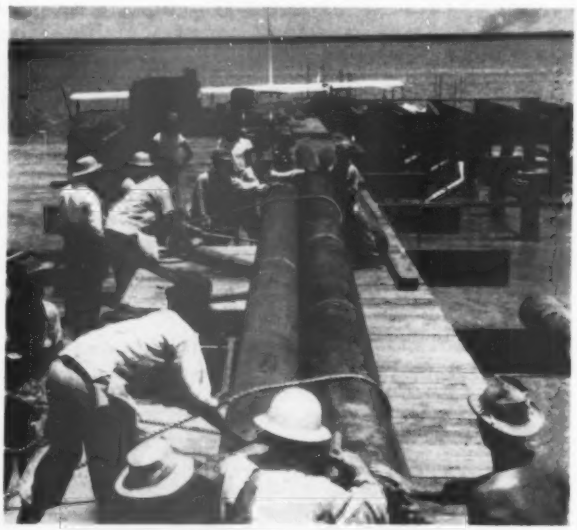
I find that today people are generally quite surprised to be told that in 1925 Houston depended upon manufactured gas made and distributed by a company whose plant had been enlarged from time to time to meet the requirements of the growing city. In that year natural gas was not used in any consequential amount in the Gulf Coastal area of Texas and Louisiana, although prior to that time natural gas was in use in San Antonio.

Up until that year, the oil production of the Gulf Coast region was coming largely from salt domes which are notably lacking in natural gas. The presence of natural gas in the Tertiary beds of the Gulf Coast region was not then even slightly envisioned. The shallow gas wells, less than 2,000 ft in depth, in Refugio and Live Oak Counties, were the basis for two natural gas lines built in 1926, one by the Houston Pipe Line Company and one by the Houston Gulf Gas Company. The competition between these two concerns, each desirous of capturing the Houston gas market, was a strong factor influencing them to carry out their plans even on modest proof of gas supplies. That was a time when lines were built mainly as a result of the efforts of those who believed that the supplies of gas would be developed if pipe line markets were established. Of course they did not require a certificate of "convenience and necessity." What we call "free enterprise" was still in full sway.

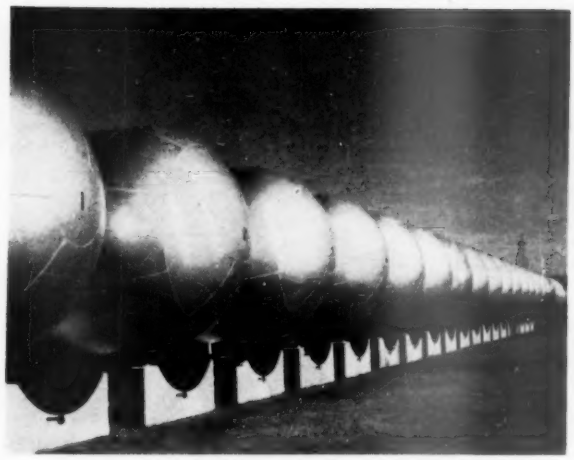
Similarly, throughout the country prior to that time lines had been built on the judgment of practical gas men as to the soundness of the enterprise, and with money supplied in many cases by oil companies interested in marketing their gas, and to some extent, by wealthy individuals.

The success of the Canadian Western Natural Gas Company's enterprise in Alberta probably was unnoted in American financial circles, but there is no doubt that the successful operation by Houston Gulf Gas Company, which had been publicly financed, became a forerunner of many somewhat similar undertakings during the next four or five years. The small bankers in New York and Chicago had had a taste of successful financing of natural gas pipe line companies. Competition to acquire similar opportunities developed among these lesser houses. Also some of the successful companies, such as Standard Oil Company of New Jersey, and others, became more interested in projects for taking natural gas longer distances to suitable markets. Hence, in the period following 1925 and up to the beginning of the depression, a great many pipe lines were built. These included the Interstate Natural Gas Company line from the Monroe field to Baton Rouge and later to New Orleans, the Mississippi River Fuel Corporation line to St. Louis, the Memphis Natural Gas Company line to Memphis and the Southern Natural Gas Company line from Monroe to Birmingham and Atlanta. The Colorado Interstate Gas Company line was built with Standard Oil and Cities Service money, from the Panhandle field to Denver. The first line of Natural Gas Pipeline Company of America was built from the Panhandle field to the Chicago area, with equity money furnished by Peoples Gas, Light and Coke Company of Chicago, Cities Service, and certain oil companies. The first stem of the Northern Natural Gas Company line from the Hugoton field northeast towards Omaha and cities in Iowa was started by the Moody-Seagraves interests, but taken over and completed by three major companies, Lone Star Gas Company, United Light and Railways Company and North American Light and Power Company. The Montana Power Company built its line from the Cutbank field to Butte, Anaconda and Helena in 1931. The Cities Service Gas Company had previously taken over the old defunct Kansas Natural Gas Company and by extending lines into Oklahoma, built that system in a great and successful enterprise. Panhandle Eastern Pipeline Company was started by a stock promotion venture, Mokan, and when the depression hit it in its unfinished and only partially financed condition, it was rescued by the Columbia Gas System with $21,000,000.

During that period from 1925 to 1930, the methods of construction and the materials used were of a sort which today would be considered highly antiquated. Pipe lines were built of thick wall lap weld pipe made from low tensile strength steel and designed to operate at up to about 500 pounds per square inch pressure. Couplings were used because the art of welding had not yet become suitably adapted. Pipe line diameters generally ranged from 14 inches to 24 inches. The first use of a 26-inch pipe was in a line, built jointly by Pacific Gas and Electric Company and Standard Oil of California, extending from the Kettleman Hills field to the San Francisco Bay area.



Workers handling pipe at a river dock.



LPG storage tanks at the London Gas Plant, Rusk County, Texas.

The Epoch 1931 to 1940

The great depression brought to a substantial halt natural gas pipe line expansion during this ten-year period. The oil industry continued its amazing growth because of the insistent increased demand for gasoline and for other oil products. As a result of the successful exploration of oil lands by use of seismic methods, an enormous inventory of natural gas was discovered in the search for oil. This gas was largely concentrated in the mid-Continent and Gulf Coast region. Gas prices in the field were generally low because of the huge surplus of gas available and the limited demands. Natural gas prices in Texas, Oklahoma and south Louisiana ranged from three to five cents in the field. And where gas was being produced with oil, no efforts were made to conserve it because there were no adequate markets. Further, the need in many fields to maintain reservoir pressures even by means of costly gas injection programs had not been generally accepted.

The Epoch 1941 to 1950

At the beginning of this period, the technology had been developed which made it possible to link the great untapped gas reserves of the Southwest with the more distant markets. The development of the use of high tensile steel, the use of welded pipe and of larger diameters, improvements in compression methods, improved equipment and methods used in pipe line construction, all led to a reasonable cost for the transportation of gas even to distances in excess of 1,000 miles.

The second World War brought about a great increase in energy requirements, particularly in the manufacturing centers of the North and East. The cost of coal increased very substantially and rather rapidly, with the result that natural gas as a fuel, particularly for house heating, but also in many manufacturing processes, was substantially cheaper than the competing fuels, coal or oil.

This made it apparent that pipe lines from the areas of large gas resources could be built to the centers of large fuel requirements. Thus, Natural Gas Pipeline Company of America built its second line from the Panhandle-Hugoton field to the Chicago area. Panhandle Eastern doubled and trebled its line capacity. Northern Natural did the same, and many other lines were built, some of which later doubled or trebled in capacity. These included the lines of Tennessee Gas Transmission Company, Transcontinental Gas Pipe Line Corporation, the change over of the Big and Little Inch oil lines to gas lines, now owned by Texas Eastern Transmission Corporation, the great increase in capacity of the old Memphis Natural Gas Company, (now called Texas Gas Transmission Corporation) Southern Natural Gas Company, and many others. The home markets in Texas, Louisiana, and Oklahoma required enormous increases in gas supplies which are being furnished particularly by United Gas Pipe Line Company, the Lone Star Gas Company, Oklahoma Natural Gas Company, and others. To meet the increased demands in California, El Paso Natural Gas Company built its lines, which have been doubled and trebled, to take gas from West Texas and New Mexico to the California markets.

Since 1950

The pace developed between 1940 and 1950 has been carried on into this year 1953. New lines are under construction, present lines are being increased by looping and by additional compression, and there are a number of projects, presently in the blueprint stage, the sponsors of which expect will be successfully completed. It is reasonable to believe that some of these anticipations will be fulfilled, and that others may not be fulfilled. In any case, there will be a continued effort to construct additional pipe line capacity so long as there are surplus gas supplies available for hungry markets. The limitation of earnings to a level just short of confiscation may be the factor which will halt expansion.

Today there are more than 18 million consumers of natural gas, situated in all parts of the nation except the Pacific Northwest and some of the Atlantic Seaboard states. Natural gas service is available today to approximately 50 per cent of the population of the nation, as against the comparable figure of about 12 per cent in 1925.

The Future

I have been closely identified with this story since 1920, and I observe and consider recent events from the standpoint of that experience. I note that annually the total gas reserve estimated as proved by the Committee of the American Gas Association continues to increase substantially. I also note that of this increase a major part is related to revisions and increases in fields previously discovered. That process will continue in the future, but in my judgment, to a lessening degree. I doubt that we can expect to continue to discover such enormous quantities of gas annually as we have enjoyed during the last 20 years. I feel that a leveling off of the enlargement processes of our pipe line industry is or should be near at hand. I am not impressed by the conclusions of the Paley Commission that by 1975 natural gas going to our markets in the United States may be of the order of 20 trillion cu ft per year. That conclusion is related more to a study of what markets would require than to a study of what the rock mass of the earth will yield.

Undoubtedly, significant additions will be made to the presently proved reserves of approximately 200 trillion cu ft. The industry will continue to expand in order to develop outlets for new reserves and to take care of a portion of the presently unsatisfied demands. It may be expected that the growth of the future will be built upon the firm foundations of technological excellence and financial soundness which have long been the hallmarks of the natural gas industry.

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Twenty Years of Growth In the Natural Gas Industry

By

John M. Hanley

Vice-President, Northern Natural Gas Co.

Member AIME

During most of the past 20-year period, the sale of natural gas to the ultimate consumer at prices below the competitive price of other fuels has been the greatest single factor stimulating the growth of the natural gas industry. Quantitatively the annual rate of production of natural gas from all sources and for all purposes in the United States has increased from approximately 1.6 to 8.6 trillion cu ft during this period, an increase of more than 500 per cent.

The growth of proven recoverable reserves during this period from about 50 trillion cu ft to 200 trillion cu ft at the end of 1952 is glowing tribute to the exploration efforts of the oil and gas industry in its search for additional supplies.

Conservation

Tremendous progress has been achieved in the field of conservation by state regulations leading to the prevention of waste and the protection of correlative rights by proration of production. Illustrative of this point is that about 20 years ago in one of the most important fields in this country, each day more than one billion cu ft of gas was being blown to the air and many well owners could not secure an outlet for their gas production. Today, there is practically no gas being wasted from this field and substantially all non-marginal wells are participating in the production of the market demand for gas.

In addition to state regulations to effect conservation, the oil and gas industry itself has initiated numerous conservation practices involving the economic utilization of natural gas. Illustrative of this is the pressure maintenance of oil fields for maximum recovery of oil. Still another important aspect of conservation during the past 20 years has been the cycling of gas, which in the reservoir contains large quantities of liquefiable hydrocarbons in the vapor phase. In this process, wet gas is produced and the liquefiable hydrocarbons are extracted from this produced gas, after which the stripped gas is reinjected into the reservoir in an effort to maintain pressures above the point at which retrograde condensation of the hydrocarbon liquids would occur in the dry sand reservoir. Eventually after the recovery of the liquefiable hydrocrabons as a part of the cycling process, the reservoir contains stripped gas which can be made available to the natural gas industry.

Field Gathering and Measurement

The installation of an electrical insulating coupling adjacent to the well has become standard practice in many fields in conjunction with the physical connection of gathering lines to wells. This insulating coupling prevents the flow of stray electric current from the gathering line down the well casing and thereby minimizes casing corrosion by galvanic action.

Much progress has been made in improving the accuracy of gas measurement during the past 20 years. The industry has quite widely accepted the construction and operating specifications of the American Gas Association. Integrating meters are becoming more and more common where it is important to know quickly the volume of gas passing through a meter at the place of measurement. Also, automatic telemetering devices are being installed in greater numbers for the purpose of recording in one place the volume and pressure of gas passing through a meter at another place.

Processing

A number of important advancements have occurred in processing gas for the recovery of products contained therein. Improvements have been made in the quality and application of absorption oils for recovery of liquefiable hydrocarbons at higher pressures than were formerly carried and in the design and operation of absorption plants. These designs and operating techniques range all the way from maximum hydro-

The Author

Processing area of The Jourdanton Gas Plant, Atascosa County, Texas. Casinghead gas is processed here.

carbon recovery to the selectivity of hydrocarbon removal for control of the heating value of the stripped gas. At least one refrigeration-type extraction plant is in operation where selective heating value control is paramount to maximum liquid hydrocarbon recovery. Predominately all gas that is moved in substantial volumes under high pressure through natural gas transmission lines has had at least its pentane and heavier components removed to prevent their condensation in the line in the course of transmission.

While the removal of sulphur compounds and water vapor from natural gas are not new developments during the past 20 years, these processes have been widely applied during this period. The shortage of sulphur during the past several years has resulted in the installation of a number of plants for the recovery of elemental sulphur. Several installations have been made where sulphur and water vapor are removed concurrently in a single vessel. Water vapor removal, or dehydration of gas, to prevent ice-like hydrate formation at the higher pressures which have become common in modern transmission lines, was initially accomplished largely by the use of liquid desiccants; however, in more recent years, plants using solid desiccants have become more widely accepted because of their ability to remove greater quantities of water from gas at higher temperatures than by plants using liquid desiccants. Practically all gas that is moved any appreciable distance under medium to high pressures is now dehydrated as a normal practice of the industry.

Compression

Twenty years ago, compression of natural gas for long line transmission was largely accomplished by horizontal engines. During the last 10 years the shortage of materials and manpower, the length of time required to manufacture horizontal compressor engines, and their resulting higher costs have contributed to the application to vertical compressors in the natural gas industry.

Gas turbine-driven centrifugal compressors are beginning to find acceptance for use in large volume low-compression ratio installations. Existing installations point toward wider utilization of this relatively new advancement in compression technique.

An advancement during the period under review is the construction of field gathering compressor stations in such a manner that they can be made to operate semi-automatically. These almost-unattended stations are equipped with automatic shut-down devices and signal systems connected to installations where personnel are present.

Transmission

Perhaps the greatest advancements in the industry over the last 20 years have been made in the transmission of natural gas through pipe lines of larger and larger diameter and at higher and higher pressures. As pipe line mileage, size, and pressures continued to increase during this period, tremendous improvements have been made in pipe line construction equipment, particularly in welding, handling, external and internal cleaning and in coating and wrapping machinery.

Metallurgical improvements in the quality of steel have resulted in the use of higher yield point steel for the manufacture of larger diameter pipe without a proportionate increase in wall thickness. Line pipe with minimum yield specifications ranging from 42,000 to 52,000 psi has become quite common. The manufacture of electric welded pipe from steel plates and its cold working after fabrication, for improvement of minimum yield point, has been developed to such an extent that most of the large diameter steel pipe being used today is made in this manner.

Twenty years ago, long, high pressure steel pipe lines were constructed with pipe having maximum diameters ranging from 24 to 26 in. Today, 30-in high pressure lines are being constructed and even 36-in lines are projected for attainment of greater transmission capacity per dollar of investment.

Tremendous progress has been achieved in the construction of pipe line, particularly in the technique of field welding of pipe. Bolted type pipe couplings have been replaced by the field welding of pipe. Acetylene welding has almost entirely been supplanted by electric arc welding in the field. Initially bare electric welding rod was used but this has been replaced by special coated rods, resulting in stronger welds. The earlier practice of using internal chill rings to back up a weld has been eliminated and better field welds are made today without the use of any internal back-up device.

Corrosion of buried pipe lines has stimulated the search for protective coatings, the use of which has now become a standard construction practice. Hot enamel coating and wrappings of various kinds are widely used today for protective coatings at the time of installation. Even with the protective coating and wrapping of pipe, certain soil conditions require additional protective devices to minimize corrosion. Important strides have been made in recent years in the testing of pipe and soil conditions and in the cathodic protection of pipe lines. Such protective devices range from the installation of anodic rods to rectifiers and wind-driven generators for the controlled introduction of electric current into and away from a pipe line at selected points.

Considerable improvement has been made in the various types and kinds of fittings which are used in constructing

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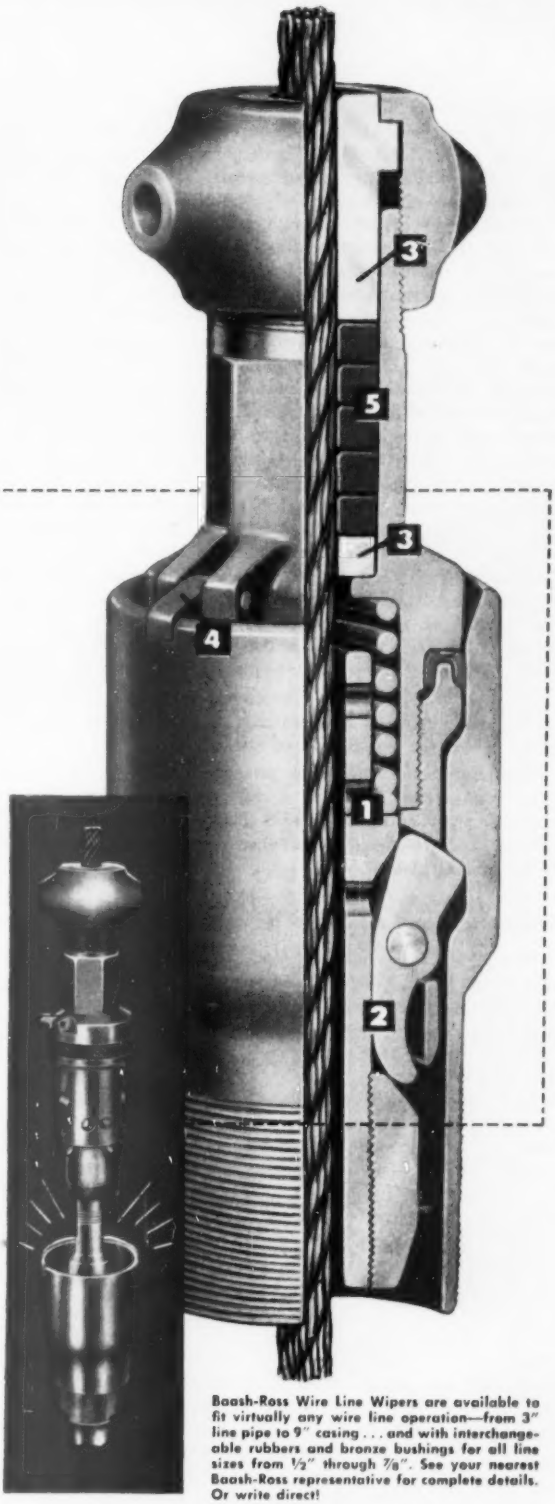

Baash-Ross Wire Line Wipers are available to fit virtually any wire line operation—from 3" line pipe to 9" casing . . . and with interchangeable rubbers and bronze bushings for all line sizes from ½" through ⅞". See your nearest Baash-Ross representative for complete details. Or write direct!

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Note the unique design of the operating mechanism. As the tools are lowered into the hole, the pack-off assembly automatically latches into proper sealed-off position in the body. Then as the tools are withdrawn, all oil and mud is wiped off the line and confined to flow lines. Even possible gas leakage is sealed off by a special packing ring between the body and packing assembly.

2 INSTANT RELEASE!

Note the simplicity and direct action of the release mechanism. The moment it is contacted by the rope socket it releases. There are no complicated mechanisms, no delay or inertia to strain a fast-moving line—because the Baash-Ross Wiper releases *instantly!*

3 SPARK-PROOF!

Note the bronze inserts both above and below the packing rubbers that prevent the steel line from contacting the steel wiper body. No chance here of steel-to-steel sparks touching off gas or oil conditions . . . *a vitally important safety feature!*

4 NON-SPINNING!

Here's another feature that's important—there's a foolproof latch that automatically locks the pack-off assembly against rotating in the body as the spiral lay of the line is pulled through the Wiper. This keeps the pack-off unit from spinning, reduces wear, increases safety and insures cleaner wiping.

5 SEGMENTED PACKING!

Take a particularly close look at the packing unit. It's not just a solid block of rubber, but consists of *many* tough rubber segments working together and so designed that they provide a *series* of wiping edges against the wire line—not just one edge. This means *cleaner* wiping.

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a large diameter, high pressure steel pipe line. The style and effectiveness of valves have improved materially in recent years by improved design of both gate valves and lubricated plug valves which are welded directly to the pipe line and provide a more effective shut-off when closed.

The efficiency of flow through pipe lines has received considerable thought and attention over recent years and has resulted in the derivation of improved flow formulae and methods of internal cleaning of lines. The need for internal cleaning of lines often became apparent by observation of loss of efficiency and by the physical movement of dust, scale, rust, etc. This became particularly evident some time after the installation of dehydration facilities at the inlet to main transmission lines. The dry gas acting as a hygroscopic agent dried out the inside of pipe lines, thereby permitting the loose, dry substances to be moved by the velocity of the gas. Some improvement in efficiency was obtained by blowing gas through the lines at increased velocities. However, this practice has been largely replaced by forcing mechanical cleaners equipped with scrapers and wire brushes through a pipe line. This procedure generally attained such good results in efficiency improvement that the running of mechanical cleaners, or "pigs" as they are called in the industry, is now usually done upon completion of the new line, before it is placed in service.

The patrol of pipe lines for timely maintenance has progressed from periodic line walking to aerial patrol by slow-flying planes for observation of needed work.

Communications have also progressed during this period from commercial telephone lines, to private lines and to high-frequency microwave radio telephone systems with both sending and receiving installations in offices, automobiles, boats, and airplanes.

Utilization and Distribution

Important improvement of load factor, with resulting lower cost of gas to the domestic consumer, has been obtained by the serving of interruptible industrial loads by natural gas pipe lines. Further improvement in load factor has been obtained by the use of strategically located underground storage reservoirs where off peak gas can be stored in summer for use in meeting peak demand in winter. This practice has grown tremendously in recent years to the extent that today some 150 fields, having an estimated ultimate storage capacity of approximately one trillion cu ft, are capable of delivering approximately 4 billion cu ft of gas per day from underground storage. One of the most recent significant developments in this respect is the apparent successful large scale storage of gas in a water bearing structure instead of the normal storage in depleted gas and oil fields.

In the field of distribution of gas, important improvements have been made. For example, arm and weight type regulators have largely given way to the use of pilot loading equipment for better control of pressure reduction. The practice of odorizing natural gas prior to distribution and consumption has become standard procedure for safety reasons; however, there is still room for improvement in an odorizing agent that will not have its warning odor practically filtered out of the gas by the soil after slow leakage from a buried line.

Regulation

Federal regulations of interstate natural gas pipe line operations is an important development of the past 20 years that has grown both extensively and intensively and, in many aspects, has become quite technical. These regulations are basically devoted to requiring certain showing to be made for Certificates of Public Convenience and Necessity for the construction and operation of facilities and over rates and earnings. Upon occasion, the showings required have been quite detailed. With respect to earnings and rates, the mechanics of getting a new rate in effect when required, due to the permitted time-lag is a matter of much concern to the pipe line industry.

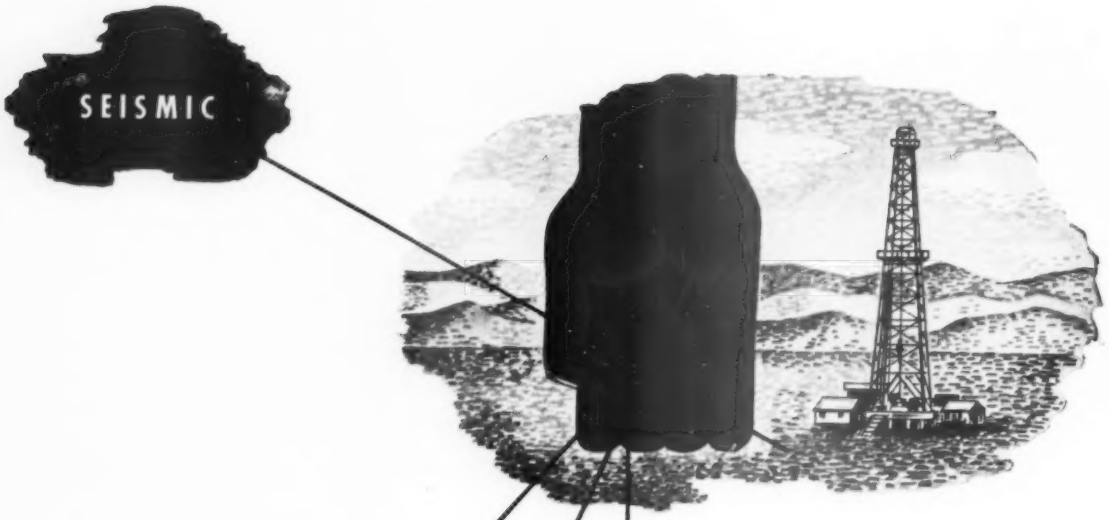
Conclusion

While the foregoing is for the most part related to the natural gas pipe line segment of the natural gas industry, important non-pipe line developments have occurred during the past 20 years. Some of the most important of these are the early growth of the volume of natural gas burned in the process of making carbon black, required in the processing of natural rubber, and the more recent decline of the use of gas for such purpose due to the apparently superior products made by the oil furnace process for use in the processing of synthetic rubber. Another significant development which has occurred is the growth of the use of gas as a raw material for the manufacture of a wide range of petro-chemical products, including inorganic fertilizers. This use is expected to continue to grow with demand for more and better chemical products.

While important developments have been made in the last 20 years in the natural gas industry, it is expected that the next 20 years will bring additional technological advancements. By application and acceptance, these will likely become common and accepted practices in an industry whose only limits would appear to be that of supply and the economics of utilization in competition with other forms of fuel and energy.

Fractionating Columns at Shell Oil Co.'s Sheridan plant.

OIL and GAS DEVELOPMENT



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Twenty Years of Advancements In Geophysical Techniques

By

Herbert Hoover, Jr.

Chairman of the Board, United Geophysical Co.

Member AIME

Within the last 20 years, geophysics has become an integral and an indispensable part of almost every petroleum exploration program. From its early beginnings, when it was generally regarded as a mysterious black box in the hands of a crystal-ball manipulator, it has now taken its place as a major working partner in virtually every exploration organization. The change has been so gradual that it is only in retrospect that one realizes the transformation that has taken place, and the great impact it has had upon the petroleum industry.

The graph in Fig. 1 shows the phenomenal growth of geophysics in the petroleum industry during the last 20 years. Some idea of the present size of the industry may be gained from the fact that the direct financial cost of geophysical operations on a world-wide basis, during 1952, excluding all other exploration costs, was approximately $400,000,000.

Large Reservoir Margin

Twenty-five years ago it was believed that most of the world's oil already had been discovered, and that the petroleum industry was headed for gradual extinction as its assets became depleted. Yet in each successive year since, more reserves have been added to the world's future supply than have been consumed in the same period and, taken on a world-wide basis, we find ourselves today with the largest margin in history.

In recent years it has been increasingly difficult to find new oil fields in the United States, particularly those of large magnitude. But this trend has been more than offset by the results of exploration abroad.

Geophysics has by no means been solely responsible for this accomplishment, but it most certainly has been one of the major contributors.

Over the last 20 years, considerable change has occurred as to the geophysical methods in vogue, and even greater changes have come about within the confines of each of the individual methods. A number of significant shifts from one method to another in the early years are shown on the graph.

In 1933, the torsion balance was beginning its rapid decline, probably due to a combination of factors. Most of the salt domes that were of the size and depth that made them easy marks for this method had already been found. The new gravity meters were much faster and cheaper to operate, and the reflection seismograph was beginning to be used as a follow-up on marginal gravity anomalies with good success. Similarly, the hand magnetometer was displaced by other reconnaissance methods that proved more applicable, and it was not until after World War II, with the development of the air-borne magnetometer, that this method again came into limited use.

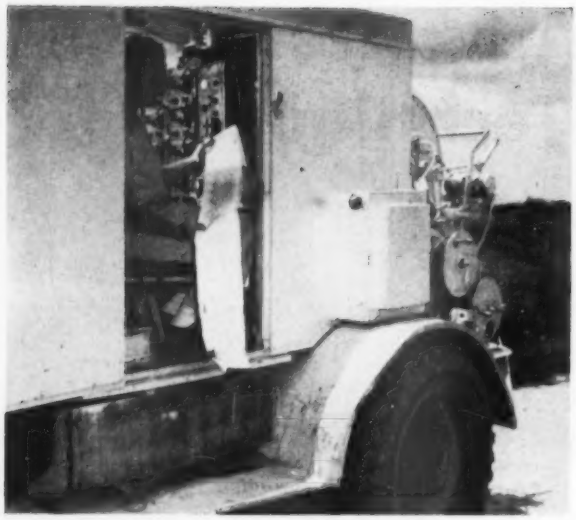
Refraction shooting for salt domes had passed its peak by 1931 for much the same reasons as affected the torsion balance. The reflection seismograph by this time had been successfully applied in Oklahoma and had been just recently introduced into the Gulf Coast, with ten crews operating at the start of 1932. From that time onward, the reflection method dominated the scene, with gravity next in magnitude as a result of its applicability as a reconnaissance tool.

Looking back from 1953, it appears that these changes were no more or less than basic economics. The more efficient methods shouldered aside the older ones. Nevertheless, it is interesting to note the rapidity with which these changes took place in the early days of the industry. This rapid reaction to technical progress is nowadays recognized as a fundamental characteristic of the geophysical exploration business.

Most of the early changes just discussed took place on the Gulf Coast because it was there that petroleum geophysics was applied the most intensively. The activity figures for the Gulf Coast and Oklahoma represented almost all there was of petroleum geophysics in those days.

Shortly after these revolutions in methods took place there

The Author



In a Seismograph recording truck, a crew member checks result of a shot.

appeared a geographical expansion into new areas of exploration. Seismic work in California was well started 20 years ago, resulting in many new discoveries in that region.

After its early beginning in Oklahoma, reflection work spread through the Gulf Coast and Texas and north through Kansas, into Illinois, Colorado, and Wyoming. Now it has passed into the Williston Basin and on north through Alberta to British Columbia, and Alaska.

Since the middle thirties more and more foreign areas have been evaluated with the aid of geophysics, often with fabulous success. Intensive exploration was carried on at an early date in Venezuela and Colombia, followed later by surveys in Trinidad, Argentina, Brazil, Chile, Cuba, Ecuador, Mexico, Puerto Rico, Nicaragua and Peru. The wide range of geological problems that had to be solved, together with the great variety of operating difficulties, presented a continuing challenge to the geologist and geophysicist at every turn.

Refraction Surveys

Coincident with the early work in South America, refraction surveys became outstandingly successful in Iran, where some of the world's largest reserves were delineated. Later on, reflection crews were operated in Saudi Arabia, Egypt, Iraq, Kuwait, Burma, Pakistan, the Persian Gulf, Turkey, Ethiopia and the Kuwait Neutral Zone. Operations also extended into Java, Sumatra, Borneo, the Philippines, New Zealand and Australia. American crews made an early appearance in Rumania, followed later by work in almost all of the other countries of Europe.

As result of these far-flung operations, and essential to them, was the advancement in instruments, techniques and transportation to cope with virtually every conceivable sort of climate, terrain and geological setting. The utilization of marsh buggies, tractors, weasels, air boats, planes and helicopters in transport problems, and the improvement of instruments as to portability, reliability and ruggedness made this advance into new areas possible.

Seismic instruments have kept pace with other developments in the industry. In 1933, a reflection crew used a four or six-trace, hand-cranked camera; string galvanometers were the rule; there was little or no control of the amplifier gain; and the seismometers weighed 20 pounds each. Today's instruments employ as many as 50 traces, embody good optics, automatic gain control, variable frequency filtering, constant paper speed and seismometers weighing ounces instead of pounds.

Seismic Equipment Research

There has been a constant striving to obtain better records. Untold man hours have gone into research on improving the quality and extending the versatility of seismic recording equipment. But the research that has been going on over the past 10 years has not been confined to instruments alone. The growth in size of *Geophysics*, the forum of the Society of Exploration Geophysicists, and the variety of articles appearing in that Journal, bears witness to the amount of fundamental research now going on. Exploration problems are being attacked all along the line, from the investigation into the mathematical physics of wave motion, on one hand, to scale model studies of typical field geologic problems on the other.

Along with instrument improvements have come many advancements in operating techniques. Such procedures as multiple seismometer patterns, air shooting, and multiple hole pattern shooting have served to remove from the map many areas previously considered geophysically hopeless.

The use of refraction techniques to solve those special problems to which it is so well adapted, is now commonplace. Instead of being considered a separate method, refraction is now employed in conjunction with reflection techniques to great advantage in many difficult areas. Some shallow water refraction work was done in 1926 in Vermillion Bay, but reflection seismograph work in the open Gulf did not begin until about 1943. The first off-shore work along the steeply shelving California coast was also started in 1943.

A diving bell for under-water gravity measurements was developed at this time but soon gave way to a remote-controlled underwater meter. Off-shore gravity operations, however, show signs of giving way to seismic work almost entirely. The added cost of seismic work is so little more than gravity under these circumstances that the added information more than offsets the increase in expense.

The airborne magnetometer was developed during the war as a submarine detector and was adapted in 1944 to aerial survey work. One of the first surveys was that of the Alaska Naval Petroleum Reserve, in 1945. It is now recognized as a useful reconnaissance tool where the size of the area to be covered merits the high starting cost.

The demands for airborne and off-shore work have forced the rapid development of electronic position-locating methods. Without these surveying devices, most modern off-shore exploration would be so handicapped as to be of little value.

Air transportation has contributed greatly to geophysics. Many seismic and gravity surveys in swamps and muskeg could not be economically carried out without airplanes and helicopters.

Economics of Geophysics

The cost of geophysical exploration has increased markedly during the last twenty years — along with almost everything else. Not only has the cost per crew or cost per year increased, but also, and more important, the cost per barrel of oil discovered has risen. In 1940, Weatherby estimated that up to then, five billion barrels of oil had been found and approximately $200,000,000 had been spent for seismic exploration. This was 4 cents per barrel. Perhaps, with other geophysical cost, the figure should be nearer 5 cents per barrel. Eckhardt's figures for the year 1952 show a dis-

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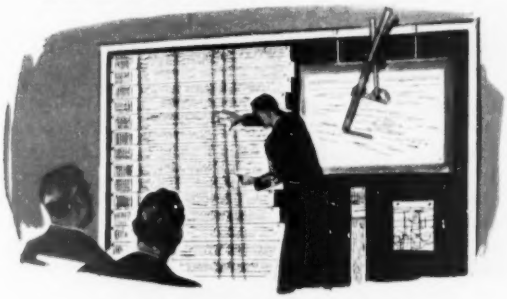

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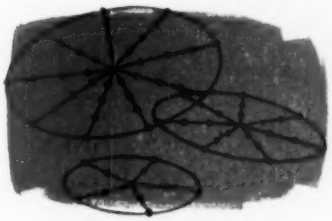

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covery of 3.3 billion barrels at an expenditure for geophysics of $400,000,000, with a resulting cost per barrel of 12 cents.

A large measure of this increase, of course, is due to inflation. A significant portion of it is also due to the increasing difficulty of finding new oilfields. Whenever a new deposit is located it is automatically eliminated from those that are yet to be found. The remaining ones become progressively more and more obscure and expensive to locate.

It is impossible to set down specifically just how much should be credited to geophysics for the discovery of the new oil fields each year. There are too many imponderables involved to arrive at even a close approximation. In fact, a considerable portion of the annual cost of geophysics should not be charged against the finding of new oil fields at all. A good part of it is spent in disproving areas which might otherwise appear to be favorable, and the saving in drilling and lease rentals are in themselves a substantial part of the total.

It was thought in 1936 that there was a trend away from the employment of independent geophysical contractors and toward the conduct of all exploration by the large oil companies themselves who could afford long-range studies. As it has turned out, however, the contractor has performed a most necessary function, and is still very much in the picture. This is especially true in foreign operations, where some of the larger contracting organizations, with experienced personnel and a wide range of equipment, have conducted a majority of the surveys in the more inaccessible parts of the world.

Currently, there is a growing realization of the need to use the results from many of the auxiliary branches of oil exploration in the ever more difficult search for new fields. Information from electric and radioactive logs, core analyses, seismic velocity measurements and many other sources must be properly integrated with the known surface and subsurface geological information to give a complete picture, if we are to make full use of the advances we have made in geophysics.

Role of the Geophysicist

The most significant change that has come about during the last 20 years is in the place that geophysics has occupied in the petroleum industry. In the early thirties, geophysics and geophysicists were largely outsiders. They were called into do a specialized job, but really "didn't belong." In this era there was a good deal of hair-splitting about the professional antecedents and the relative merits of the geologist *vs* geophysicist. This was usually accompanied by the claims and counterclaims of each group for the credit of finding this or that oil field — none of which was conducive to the full utilization of an exceedingly useful tool.

Today, the old distinctions between geologist and geophysicist are rapidly melting away. Many of the younger men who have entered the field of geophysics in the last 20 years received their basic college training in geology. Likewise, most of the progressive oil companies insist that their younger geologists should serve their apprenticeships on geophysical crews as a part of their training and experience. The colleges, also, are including a broader grounding in physics, mathematics, and engineering in their geological curriculum. This is all part of a well-defined trend.

In a number of organizations today, the title of either geologist or geophysicist is used primarily to designate the position which a man is momentarily occupying. He may switch back and forth numerous times during his professional and administrative career. Furthermore, an increasing number of geophysicists are finding their way into managerial and executive positions of oil company exploration departments.

In addition to having a thorough and detailed knowledge of the geophysical tools that they are using, these men have gained wide experience in the organization and administration of domestic and foreign field operations. Regardless of any future increase or decrease of geophysical activity, these men form a permanent and extraordinarily valuable group within the petroleum industry.

Future Developments

One cannot review the past 20 years of petroleum geophysics, even briefly, without speculating on what the future will bring forth. There is always the possibility that some new gadget will come along to make the job of finding oilfields surer and easier. If it does, the industry will certainly adopt it overnight. There are some people who even foresee the doom of the entire industry unless it is forthcoming immediately. But the probability is that they will be wrong on both counts.

The petroleum industry has for many years been spending record amounts for research on new and improved methods of exploration. Every possible lead seems to have been investigated. But, so far, no radical developments have appeared.

Rather, the trend of the future appears to be along the line of steady and continued improvement of the basic methods already in use. The greatest opportunities seem to lie in the field of geophysical interpretation, together with the intimate correlation of the geophysical findings with all other available surface and subsurface information. This is a job that must be solved by the exploration management, the geologist and geophysicist in close and constant cooperation. Some oil finding organizations seem to be farther along in this phase of organization than others, and it is no accident that they also seem to find the most oil.

Development of Techniques In Reserve Estimation

By

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Member AIME

During the past two decades, much scientific and engineering knowledge has been obtained in the petroleum industry relative to recovering oil and gas from reservoirs. Most of this information assists in estimating quantities of oil and gas in place and recoveries which may be expected over the life of the field. Within a limited space it is impossible to discuss all of the new information in detail or to make reference to the large number of technical papers and books which record our growing storehouse of knowledge.

In the early thirties, the producing industry was undergoing its most significant transition from uncontrolled production to controlled production under proration. At this time there was a rapid increase in the number of engineers and scientists who devoted their time, both in the field and in the laboratory, to production problems. Such studies naturally extended beyond the bounds of leases and encompassed the entire reservoir. The term, reservoir engineering is used today to describe the combination of geological and engineering knowledge and techniques employed in treating reservoirs, including the estimation of reserves. This term was uncommon in 1935, for the writer finds a reference in a private report on that date which suggests use of the term "reservoir engineer."

Prior to proration a production decline curve plotted as a straight line on logarithmic paper would give a reasonable estimate of future oil production for certain types of fields. The determination of reservoir pore volume from a geological study of well information was one method of determining oil and gas in place. Gas reserves were predicted by pressure decline methods at that time as well. During the past 20 years, the decline curve has faded from the scene and many new concepts have been added.

The material balance has been developed as a tool in determining oil in place from reservoir pressures and productional data. The presence of connate water has modified the procedures for determining oil and gas in place from pore volumes. Well logs and laboratory tests augment information on the porosity of producing horizons. Relative permeability concepts make possible the determination of oil recoveries under different types of operation. Before discussing the effect of these lines on the estimation of reserves, a brief review of these new tools and information will be given.

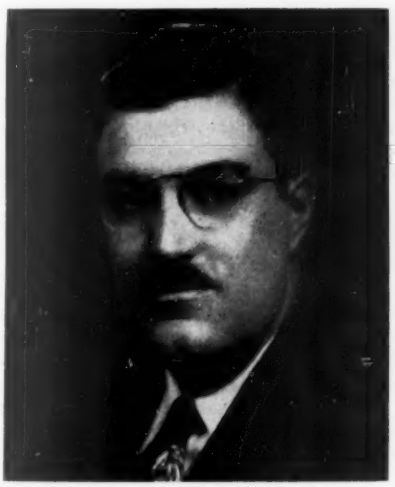
New Concepts Which Concern Reserve Estimation

Every phase of petroleum reservoirs has received study. The phase behavior of hydrocarbon fluids, both gas and liquid, has received considerable attention. The mechanism by which oil is recovered became of intense interest soon after the engineer turned his attention to the complete reservoir. Quantitative knowledge of connate water content of reservoir media became imperative once the full significance of its presence was felt. Mass analyses of cores and routine electric well logs on every well have converted procedures which were accepted as qualitative 20 years ago into quantitative methods. The relative flow of two fluids in a porous medium when accounting for their properties is known as relative permeability. That this relative permeability for a fluid depends upon the percentage saturation and nature of the media is most significant in oil recovery. Calculations of oil recoveries from reservoirs by production under different specified ideal conditions has shown the benefits from the controlled water drive or pressure maintenance. Thus, oil recoveries can be predicted only when the operating conditions are stated.

Properties of the Hydrocarbons

Crude oil contains dissolved gas which contributes to its liquid volume in the reservoir and to such properties as viscosity and surface tension. At saturation pressures of 3,000 pounds per sq in or more, a reservoir crude oil is likely to have a surface tension of 2 dynes per cm or less as compared to 20-30 dynes in the stock tank without the dissolved gas. The viscosity ratio of the oil to the gas may well be below 3 in the reservoir as compared to some 50 or more in the stock tank. The dissolved gas may contribute over one-half of the volume of the liquid phase.

The Author



Retrograde condensation may occur when the pressure is reduced on high pressure gas fields, because the oil is more soluble in high pressure gas than in gas at moderate pressures. Natural gases have been known to deviate from ideal gas behavior for a long time. This deviation has been studied thoroughly and shown to be a function of pressure, temperature and gas composition. The latter may be described by means of gas gravity for normal hydrocarbon gases.

Reservoir Mechanisms

The ultimate source of the pressure which brings oil to the well bore is important in understanding oil recovery. Water displacement by the underlying brine which expands throughout the aquifer and regenerates at the outcrop, is an efficient mechanism when under proper control. When brine fails to move into the space occupied by crude oil flowing to a well, the pressure decreases and the equivalent space may be filled with gas released from solution in the crude oil. This mechanism, known as dissolved gas drive, is least efficient because the relative permeability of the gas becomes very high as soon as the percentage of gas phase becomes over 20-30 per cent. In simple terms, the gas can boil out of the crude oil and pass to the wells without driving much oil with it once gas channels are thoroughly established.

Oil will drain by gravity from porous media to give high recoveries when the conditions are such that it can be recovered from the lower portions of the reservoir. Gravity drainage is a factor in gas drive fields, whether by dissolved gas or by a combination of dissolved gas and gas cap gas. When water drive is slower than production rates, a field may become a combination of water drive and gas drive.

One would be reluctant to give an opinion concerning oil reserves from a given reservoir until he knew the mechanism of the displacement. The injection of both gas and water can artificially control the mechanism. Unitization of the reservoir is often necessary for such operations. Studies of the transmission of pressure through aquifers connecting petroleum reservoirs within the same geological strata enlarge our perspective with regard to water drive mechanism. This information was a prerequisite to developing techniques of augmenting natural water drive by injection of produced brine or water. It becomes clear that projected operations for a reservoir can change the expected oil recovery.

Connate Water

Connate water is present in the interstiees of the porous reservoir rock in most reservoirs because it would not drain out in the presence of the oil and gas. In fact, the porous media when wet by water may imbibe the water from below by capillary effeots even when filled with hydrocarbon. The presence of connate or interstitial water initially was observed from core analyses. More reliable data on water in place in the reservoir media have come from cores taken with oil base drilling mud. Laboratory tests for the equilibrium connate water include the capillary pressure method in which the water content of a core plug surrounded by gas but in contact with water on the bottom is measured after the water is allowed to drain from it. To shorten the test, a centrifuge technique has been employed. Also, electric logs of wells may be used to determine connate water with sufficient auxiliary data.

The connate water content is highest for low permeability media or lowest for high permeability media. A few reservoirs may not have had any connate water and are sometimes described as "oil wet." Others have so much interstitial water that it is produced along with oil or gas. Many commercial fields have connate water contents in the range of 15-35 per cent of the pore space. In gas reserve estimates, these contents become direct factors for reducing the pore volume and gas reserve. For oil fields, the oil in place is reduced directly but the oil recovery may increase percentage-wise for higher water contents, and thus partially off-set part of the effect of its presence.

Methods of Determining Pore Space

The increase in technical personnel in the producing industry resulted in demands for more quantitative data. Cores formerly taken for geological information alone, now are analyzed for porosity and permeability. Techniques for coring also have improved notably.

Electrical logging of wells is commonly practiced as a routine operation after the drilling of most wells. These logs, including the MicroLog, assist in giving rather accurate values for the thickness of producing formations. When a small amount of core data is available to standardize the electrical measurement, quantitative determination of pore space may be made from it.

Unique methods of examining drill cuttings have been devised to find the porosity of the productive sand. A correlation of the appearance of cores and cuttings with data on cores assists in making the examination of cuttings by the geologist more quantitative.

Relative Permeability

The permeability of a core plug may be determined by passing a gas through it under measured conditions. If two fluids are present in the interstices, both fluids may flow and the permeability computed from the flow of the individual phases. The ratio of the permeability so measured to that obtained with a single phase is relative permeability. Relative permeability depends upon the porous media and upon the volume percentage distribution of fluids in the pore space.

Relative permeabilities may be determined on a given porous medium with oil and water; and with oil and gas. Such data permit computation of oil movement in the reservoir during the production process and recovery values under specified conditions.

Producing Rates

At one time, reserves were quoted without reference to the mechanism by which they were to be produced. With natural gas reserves, it is necessary to have information on the productivity of the horizon in the form of deliverability curves. Such plots of the logarithm of difference in squares of pressures against log of flow rate permit the prediction of well capacities during pressure decline on the reservoirs.

The productivity index of a well is a measure of its ability to produce oil with pressure reduction at the well bore. A consideration of well productivity in a given reservoir has significance in interpreting its oil reserve.

ESTIMATION OF GAS RESERVES

Natural gas dissolved in crude normally would have a reserve determined along with the oil reserve and is not treated here. Reserves in natural gas or condensate reservoirs are most likely to be determined at some time by means of the pore volume from geological maps. At various stages in the producing life of the reservoir, the reserve may be computed by the material balance method.

The basic data required for the pore volume method are:

1. Thickness and extent of producing horizon above water, if present. An isopac map is a convenient device for this information.

2. The porosity of the producing horizon, from core analyses, well sample logs, and electric logs.
3. The connate water content of the reservoir media.
4. The temperature in the reservoir.
5. The pressure in the reservoir. This value may be computed from well head pressures by adding the gas column.
6. The compressibility factor for natural gas, either measured or calculated from pressure, temperature, and gas gravity.

The volume of natural gas contained in a cu ft of space is computed from the gas law and multiplied by the volume of pore space containing gas, to give the total reserve. This general procedure is not new, but refinements have been made in determining all of these factors.

The reserve may be computed for natural gas by a material balance from pressure decline in the reservoir, gas production and the assumption of a constant reservoir volume. The volume of gas contained in a cu ft of pore space may be computed at the initial and at the final pressure condition. The difference in gas content represents the yield of gas per cu ft of gas space in the reservoir. This value, divided into the gas production, gives the gas pore space and hence the reserve. When the reservoir is changing in volume by water intrusion, its rate of intrusion per unit of pressure drop could be estimated and included to compensate for the volume change.

One problem which arises in this method of estimating gas reserves is the lack of equilibrium between the pressure throughout the reservoir and that at the wells which have been closed in a short period. Methods of computing the eventual build-up in well pressures based on unsteady gas flow should assist in improving the accuracy of the method.

Once a gas reserve has been established, the question naturally arises as to how and when is this gas to be made available for transportation to market. This involves the determination of well deliverability, the number of wells to be drilled, and a computation of annual production with accompanying pressure decline. Such a schedule may be computed by assuming that the reservoir is of constant volume and that water does not displace the gas. The significant reserve of gas is that portion of the total gas in place which can be produced down to a reservoir pressure at which producing rates become uneconomic.

In case the gas field is under water drive, well productivity would not decline seriously until water reached a given well. In this case the water intrusion and well patterns would be a factor. Some trapping of gas by the encroaching water would be expected. Laboratory tests indicate that at least 10 per cent of the gas would not be displaced and that a much larger percentage could be retained in the sand through which the water has passed. The significant reserve would be that gas which can be displaced by the water before the well production is reduced to an uneconomic limit by water intrusion.

Condensate Reservoirs

The condensate content of a reservoir fluid can be determined for the pressure decline conditions encountered during production by laboratory examination of a well effluent sampled properly. The phase behavior also can be computed from the composition of the reservoir fluid. Calculations of the recovery of condensate can be made for pressure depletion or cycling plans by taking into account the well spacing patterns, pressure drop adjacent to well bores, variation in permeability of the producing formation, and possible segregation or movement of retrograde condensate in the reservoir.

ESTIMATION OF OIL RESERVES

Oil reserves should be distinguished as oil in place or oil recovery*. Oil in place may be computed by a material balance or from the pore volume of the reservoir.

Oil in Place

The pore volume method requires the following information:

1. Reservoir extent, thickness, porosity, and connate water as with gas reserves.
2. The formation volume factor to account for the shrinkage of the reservoir oil as it flows to the stock tank.

The oil in place is the volume of hydrocarbon pore space divided by the formation volume factor. The dissolved gas reserves, as gas in place, would be computed from the oil in place and the solubility of the gas as cu ft of gas per barrel of residual oil.

The material balance method requires the following information:

1. Reservoir pressure history.
2. Behavior of reservoir oil upon pressure reduction at reservoir temperature, gas solubility and formation volume factor.
3. Oil and gas production history.
4. The compressibility factor of the gas in the reservoir.
5. Presence and extent of an initial gas cap.
6. The nature of any water movement into the reservoir upon pressure reduction.

By a balance one computes the oil which must be in the reservoir to have maintained the reservoir pressure in accordance with the history of the field. If well pressures after oil production are not up to the equilibrium reservoir pressure, the material balance method will show a smaller quantity of oil to be present than is actually the case.

Whenever possible, the reservoir engineer would check one method of determining the oil in place against the other method.

Oil Recovery

The determination of the oil in place in a reservoir is only the first step to the estimation of oil recovery. The following information is necessary for computing the oil recovery:

1. The Reservoir Mechanism: water drive, gas drive, or combination.
2. Fluid injection, gas or water.
3. Drilling and production schedule, well location, permissible water-oil or oil-gas ratios on wells.
4. Permeability of producing strata, relative permeabilities of fluids, variation in permeability between layers.
5. Properties of the reservoir fluids.

The recoveries may be computed for specified ideal conditions by flow formulas adapted to a particular case. Recoveries have been calculated for typical reservoir conditions with generalized parameters. Electrical computing machines have been adapted to analyze reservoir behavior under a series of postulated conditions. Such computations may include compensations for final stages of production in gas drive reservoirs when gravity drainage occurs.

It should be stated that judgment based on experience has always been a factor in estimating reserves. Today, quantitative data play a much more important role in estimating reserves than they did 20 years ago. However, final decisions on a particular reservoir still include judgment as a significant factor.

*It is customary to speak of either item as stock tank barrels with a formation volume factor to give reservoir barrels.

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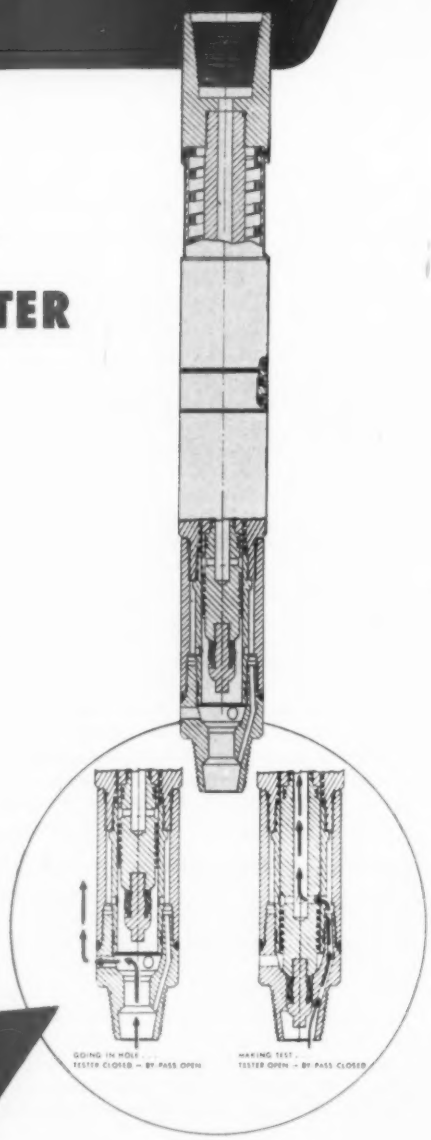

Hydro-Spring Tester—Patent Applied For

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IT'S DALLAS

1953 FALL MEETING SITE - - - A COSMOPOLITAN CITY

When pioneer John Neely Bryan, Dallas' founder, put up a little one-room log cabin on the banks of the Trinity River slightly over a hundred years ago, he couldn't foresee that he was laying the ground work for a city that would become a business, cultural, and fashion center of the Southwest. And his intentions to start a trading business with the Indians has expanded to one of the nation's leading markets.

Dallas, or "Big D," as it is affectionately called, is in a strategic geographic location in the heart of Northeast Texas. Its concentration of business and buying power and the fact that it really isn't far from anywhere has made it one of the leading commercial centers of the country.

For the approximately 1,500 leading petroleum engineers and 300 ladies who will gather in Dallas on October 18 for the AIME Petroleum Branch Fall meeting, Dallas has a variety of things to offer. It is a good business town, but it is a good pleasure town, too, and between technical sessions, luncheons and banquets, and committee meetings, the visiting member can find almost anything he is looking for in this metropolis of 532,000.

The meeting happily coincides with one of the city's outstanding yearly activities — the State Fair of Texas. Although the ladies are scheduled for a tour of the Fair while their husbands are busy with the meeting, there is so much to see, they will probably be willing to go back for a second look. The Fair offers its Midway, Cotton Bowl games, industrial, food, and fashion exhibits, and its special feature this year, the Ethel Merman Show.

The Adolphus and Baker Hotels will house the meeting, and are located diagonally across from each other on Commerce Street. They are only steps away from excellent restaurants and Dallas' leading department stores.

Of special interest to the Petroleum Branch member is the fact that Magnolia Petroleum Company and The Atlantic Refining Co. have research laboratories, located on the Duncanville Road, and 4500 Mockingbird Lane, respectively.

For the gourmet there are Swedish, Italian, German, Greek, Chinese, and Mexican foods. And for the sightseer, there are the Museum of Natural History, and Dallas' Museum of Fine Arts. For the nature lover there is White Rock Lake, a 1,200-acre body of water 15 minutes from town, which offers picnicking, fishing, sailing, and a view of the handsome homes bordering it.

These things, together with the city's golf courses, tennis courts, industrial plants, rodeos, and a 60-acre zoo blend together to make Dallas a truly cosmopolitan city.

E. R. Brownscombe
Atlantic Refining Co.
Chairman, Dallas Section

At any party, or convention, or any Petroleum Branch Fall Meeting, there is always a group of people who are responsible for the planning and executing of the activities. The persons putting out the most elbow grease this year are your hosts — the members of the Dallas Local Section (exception: Douglas Ball, Washington, D.C.). On this page are pictured the Fall Meeting Officers who have been working for a bigger and more interesting meeting program since this time last year.

The small details of exhibits, presentation of technical papers, housing, publicity, registration, entertainment, etc., have been the problem of these men, but we believe that you will agree that they were solved very expertly.

J. H. Murrell
DeGolyer & MacNaughton
General Chairman

Dallas Section and Meeting Committee Heads

John Wisenbaker
Core Laboratories
Entertainment

R. J. Bradley
Bradley, Oliver & Assoc.
Finance

R. J. Bethancourt
Sun Oil Co.
Arrangements

Kenneth Robbins
Otis Pressure Control
Registration

Douglas Ball
Consultant
Economics Committee

Brad Mills
A.A.O.D.C.
Publicity

Ruford Madera
Republic Natural Gas
Hotels

Mrs. Don J. Shaw
Ladies Activities

R. T. Bright
Mercantile Natl. Bank
Vice-Chairman,
Dallas Section

Tom Morton
Halliburton
Sec.-Treas.,
Dallas Section

PROGRAM

of

Papers and Activities

PETROLEUM BRANCH, AIME, FALL MEETING

Adolphus and Baker Hotels, Dallas, Texas, October 18-21, 1953

(All papers shown are subject to change or withdrawal)

Sunday, October 18

1:00 p.m. to 5:00 p.m. — PETROLEUM SECTION CONFERENCE — Cactus Room, Adolphus, Raymond E. Howard, Conference Chairman, Presiding

1:00 p.m. to 9:00 p.m. — ADVANCE REGISTRATION — Ballroom, Adolphus

Monday, October 19

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Ballroom, Adolphus

9:00 a.m. to 11:00 a.m. — FIELD CASE HISTORIES — Roof Garden, Adolphus

Presiding: E. R. Brownscombe and William H. Justice

Opening Remarks by Claude R. Hocott, Chairman, Petroleum Branch, AIME

278-G: *History and Performance of the Coldwater Oil Field, Michigan*, by C. R. Criss and R. L. McCormick, Sohio Petroleum Co.

331-G: *Performance of a Water Drive Field, Torchlight Tensleep Reservoir, Wyoming*, by F. H. Calloway and F. M. Stewart, Stanolind Oil & Gas Co.

280-G: *Pressure Maintenance by Gas Injection in the Brookhaven Field, Mississippi*, by J. B. Justus, R. W. Cassingham, C. R. Blomberg, and W. H. Ashby, Jr., The California Co.

9:30 a.m. to 12:00 m. — PRODUCTION EQUIPMENT — Crystal Ballroom, Baker

Presiding: Richard T. Bright and Don L. Harlan

Opening Remarks by Claude R. Hocott, Chairman, Petroleum Branch, AIME

281-G: *Metallurgical Aspects of Sucker Rods and Their Oil Well Performance*, by Frederick J. Radd and R. L. McGlasson, Continental Oil Co.

282-G: *A New Gas Lift System*, by R. P. Vincent and L. B. Wilder, Stanolind Oil & Gas Co.

283-G: *Automatic Lease Operations, Weeks Island Field, Louisiana*, by Turner P. Northern, Gulf Oil Corp.

284-G: *Pump Volumetric Efficiency — A Study of the Effects of Pumping Variables*, by C. A. Connally, C. R. Sandberg, and N. Stein, Magnolia Petroleum Co.

9:30 a.m. to 11:00 a.m. — For the Ladies — Milk Punch and Breakfast, Engineers' Club of Dallas, 206½ Browder Street

12:30 p.m. — PETROLEUM BRANCH WELCOMING LUNCHEON — Roof Garden, Adolphus, H. N. Mallon, President, Dresser Industries, Speaker; Subject: "The Petroleum Engineer's Dream — Ideas to Realities."

3:00 p.m. to 5:00 p.m. — MEMBERSHIP OPEN FORUM with Petroleum Branch Executive Committee — Crystal Ballroom, Baker

3:00 p.m. to 5:00 p.m. — ECONOMICS AND MANAGEMENT — Cactus Room, Adolphus

Presiding: A. H. Crawford and Kenneth E. Hill

292-G: *Allocation of Producing and Finding Costs Between Crude Oil and Natural Gas*, by E. E. Hunter, Humble Oil & Refining Co.

293-G: *Oil Shale Phase of Synthetic Fuel*, A. C. Rubel, Union Oil Co. of California.

294-G: *So-Called Conservation Versus Realistic Economics*, by Charles J. Deegan, Petroleum Consultant.

7:00 p.m. to 10:00 p.m. — COCKTAILS AND BUFFET DINNER, DeGolyer & MacNaughton, Hosts, Brook Hollow Golf Club.

Tuesday, October 20

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS, Ballroom, Adolphus

9:00 a.m. to 12:00 m. — DRILLING FLUIDS, Roof Garden, Adolphus

Presiding: Preston E. Chaney and Brad Mills

288-G: *An Inexpensive Mud for Deep Wells*, by H. F. Coffer and Roscoe C. Clark, Continental Oil Co.

289-G: *Filtration from Mud During Drilling*, by C. K. Ferguson and J. A. Klotz, California Research Corp.

290-G: *Mechanical Treatment of Weighted Drilling Muds*, by R. S. Hoch and Roy A. Bobo, Phillips Petroleum Co.

291-G: *Drilling Mud Control in the Southwest Louisiana Coastal Area*, by C. R. Claus and G. A. Standish, Magnolia Petroleum Co.

8:30 a.m. to 12:00 m. — RESERVOIR FLUIDS — Crystal Ballroom, Baker

Presiding: Ruford F. Madera and John D. Wisenbaker

297-G: *Viscosity of Hydrocarbon Gases Under Pressure*, by David B. Burrows, Rice Institute, and Riki Kobayashi, Continental Oil Co.

298-G: *Effect of Pressure and Temperature on Oil-Water Interfacial Tensions for a Series of Hydrocarbons*, by Hohey El-Din Hassan, Ralph F. Nielsen, and John C. Calhoun, Pennsylvania State College.

327-G: *Equilibrium Vaporization Ratios for Reservoir Fluid Containing a High Concentration of Hydrogen Sulfide*, by H. A. Vagtborg, Jr., The Pure Oil Co.

340-G: *Solution of the Equations of Unsteady-State Two-phase Flow in Oil Reservoirs*, by W. J. West and W. W. Garvin, California Research Corp., and J. W. Sheldon, International Business Machines Corp.

For Discussion Only:

296-G: *A Method for Determination of Average Pressure in a Bounded Reservoir*, by C. S. Matthews, F. Brons, and P. Hazebroek, Shell Oil Co.

12:00 m. — For the Ladies — LUNCHEON AND STYLE SHOW — Mural Room, Baker

1:15 p.m. to 5:00 p.m. — PRODUCTION OPERATIONS AND GEOLOGICAL ENGINEERING, Roof Garden, Adolphus

Presiding: Raoul J. Bethancourt and Michael T. Halbouty

300-G: *Plugging Off Water in Fractured Formations*, by G. C. Howard and P. P. Scott, Jr., Stanolind Oil & Gas Co.

312-G: *A Ten-Pound Cement Slurry for Oil Wells*, by Roscoe C. Clark, Jr., Continental Oil Co.

313-G: *A Simplified Cementing Technique for Recompletion Operations*, by T. A. Huber, G. H. Tausch, and J. R. Dublin, III, Humble Oil & Refining Co.

303-G: *Red Fish Bay Field, Nueces County, Texas*, by O. J. Shirley and D. R. Dunham, Shell Oil Co.

342-G: *Review of the Geology and Development in the Uintah Basin*, by Dorsey Hager, Consultant.

1:30 p.m. to 4:30 p.m. — RESERVOIR MECHANICS — Crystal Ballroom, Baker

Presiding: Henry J. Gruy and H. L. Long

307-G: *A Study of Displacements in Microscopic Capillaries*, by CHARLES C. TEMPLETON, Shell Development Co.

308-G: *Displacement Experiments in a Consolidated Porous System*, by J. S. LEVINE, Shell Development Co.

309-G: *Oil Production After Breakthrough — As Influenced by Mobility Ratio*, by A. B. DYES, B. H. CAUDLE, and R. A. ERICKSON, The Atlantic Refining Co.

For Discussion Only:

332-G: *Dimensionally Scaled Experiments and the Theories on the Water-Drive Process*, by G. A. CROES and N. SCHWARZ, De Bataafsche Petroleum Maatschappij, The Hague.

5:30 p.m. to 7:00 p.m. — COCKTAIL PARTY — Bradley, Oliver, and Associates, and Core Laboratories, Hosts, Dallas Petroleum Club, Baker

7:00 p.m. to 12:00 p.m. — PETROLEUM BRANCH BANQUET AND DANCE — Crystal Ballroom, Baker, music by Freddie Martin and his Orchestra.

Wednesday, October 21

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Ballroom, Adolphus

9:00 a.m. to 12:00 m. — LOGGING, Roof Garden, Adolphus

Presiding: Kenneth F. Anderson and R. B. Gilmore

310-G: *Interrelation of Resistivity and Potential of Shaly Reservoir Rocks*, by F. M. PERKINS, JR., H. R. BRANNON, JR., and W. O. WINSAUER, Humble Oil & Refining Co.

311-G: *A Contribution to Electrical Log Interpretation in Shaly Sands*, by A. POUPON, M. E. LOY, and M. P. TIXIER, Schlumberger Well Surveying Corp.

301-G: *Electric Logging in Thin Beds*, by LEENDERT DEWITTE, Continental Oil Co.

302-G: *An Experimental Investigation of the S.P. and Resistivity Phenomena in Dirty Sands*, by M. R. J. WYLLIE and P. F. SOUTHWICK, Gulf Research & Development Co.

9:00 a.m. to 12:00 m. — SECONDARY RECOVERY, Crystal Ballroom, Baker

Presiding: Lewis Finch, Jr. and W. W. Wilson

314-G: *The Effect of Surface and Interfacial Tensions on the Recovery of Oil by Water Flooding*, by HARVEY T. KENNEDY and ERASMO T. GUERRERO, A&M College of Texas.

315-G: *Water Flooding Facilities, Salem Unit, Marion County, Illinois*, by R. L. LIVINGSTON, The Texas Co.

316-G: *Twelve Years of Gas Injection in a Frio Sand*, by B. T. MILLIKIN, JR., Continental Oil Co.

325-G: *Estimated Effect of Vertical Fractures on Secondary Recovery*, by PAUL B. CRAWFORD and R. E. COLLINS, Texas Petroleum Research Committee.

11:00 a.m. to 2:00 p.m. — For the Ladies — VISIT TO STATE FAIR OF TEXAS

1:30 p.m. to 4:30 p.m. — WELL COMPLETION — Roof Garden, Adolphus

Presiding: Tom E. Morton and Charles H. Hudson

317-G: *Reservoir Fracturing — A Method of Oil Recovery from Extremely Low Permeability Formations*, by L. E. WILSEY and W. G. BEARDEN, Stanolind Oil & Gas Co.

318-G: *The Mechanics of Formation Fracture Induction and Extension*, by WILLIAM J. MCGUIRE, EUGENE HARRISON, and W. F. KIESCHNICK, JR., Atlantic Refining Co.

319-G: *Effectiveness of Gun Perforating*, by T. O. ALLEN and J. H. ATTERBURY, JR., Humble Oil & Refining Co.

320-G: *Practical Aspects of Gravel Packing*, by C. J. RODGERS, Gulf Oil Corp.

1:30 p.m. to 4:30 p.m. — NATURAL GAS TECHNOLOGY, Crystal Ballroom, Baker

Presiding: Kenneth W. Robbins and William H. Speaker

321-G: *The Combustion Gas Turbine — Historical Development and Present Day Applications to Natural Gas Pipelines*, by TRACY S. PARK, JR., Tennessee Gas Transmission Co.

322-G: *Multi-Phase Co-Current Flow of Fluids in Horizontal and Vertical Pipes*, by R. L. HUNTINGTON, The University of Oklahoma.

323-G: *Design of Two-Phase Gathering Pipelines*, by OVID BAKER, Magnolia Petroleum Co.

330-G: *The Isochronal Performance Method of Determining the Flow Characteristics of Gas Wells*, by M. H. CULLENDER, Phillips Petroleum Co.

For Discussion only:

341-G: *Analysis of Natural Gas Well Back Pressure Test Data*, by DAVID CORNELL, Texas Petroleum Research Committee.

5:30 p.m. to 10:00 p.m. — COCKTAIL PARTY AND BARBECUE SUPPER, Dresser Industries, Host, Security Engineering Co. Plant, Dallas

Exhibitor's Guide

Exhibitor	Booth Number
American Iron & Machine Works Co.	1
Associated Equipment Co.	7-B
Atomic Energy of Canada, Ltd.	14
B & W, Incorporated	6
Baker Oil Tools, Inc.	26
Camco, Inc.	19, 20
Core Laboratories, Inc.	8
Dia-Log Co.	12, 13
Dowell Incorporated	9
Dresser Industries, Inc.	16, 17
George E. Failing Co.	18
Garrett Oil Tools, Inc.	2
Geolograph Co., Inc.	27
Grove Regulator Co.	15
Halliburton Oil Well Cementing Co.	4
Harbison Fischer Mfg. Co.	7
HOMCO	30
Johnston Testers, Inc.	10, 11
Kimray, Inc.	29
Lane Wells Co.	24
McEvoy Co.	28
Merla Tool Co., Inc.	5
Otis Pressure Control, Inc.	25
Schlumberger Well Surveying Corp.	21
Shaffer Tool Works	22
Sola Catalytic Co.	3
Welex Jet Services	23

Liedholm

Harlan

Justice

Chaney

Speaker

Program Arranged By Technology Committee

The function of the Petroleum Branch Technology Committee is to gather technical papers of suitable quality to be presented at the Annual Mid-Continent Fall Meeting, Oct. 18-21, 1953, and later to be considered for publication in the *Journal of Petroleum Technology*.

The approximate 43 papers for this year's meeting were grouped according to subject and will be presented in the ten technical sessions of the three-day meeting. Each session will have two presiding officers. The program on page 87 indicates time, place, and subject of each session.

The Economics and Management session on Monday in the Cactus Room of the Adolphus Hotel, will be comprised of three papers, which were secured by Douglas Ball, Consultant, Washington, D. C., Chairman of the Committee; and Kenneth E. Hill, Chase National Bank, New York, Vice Chairman.

Available abstracts of papers to be presented at the meeting are listed numerically by their "G" number on page 91, in order that the member may have an idea of the text of each paper and can determine which session he wishes to attend. The author of each paper, and his company affiliation is also shown.

The Technology Committee is made up of the Committee Chairman and four Vice Chairmen for the divisions of Drilling, Production, Natural Gas, and California. These men are: William H. Justice, La Gloria Corp., Corpus Christi, Technology Committee Chairman; Preston E. Chaney, The Texas Co., Beaumont, Vice Chairman, Drilling: Don L. Harlan, The Texas Co., Houston, Vice Chairman, Production; W. F. Speaker, Magnolia Petroleum Co., Dallas, Vice Chairman, Natural Gas; and C. C. Liedholm, Signal Oil & Gas Co., Los Angeles, Vice Chairman, California. Committee members are: Drilling — W. F. Kieschnick, Atlantic Ref. Co., Dallas; George R. Gray, Baroid, Houston; A. H. Crawford, Crawford Drilling Co., Shreveport; Louis G. Chombart, Amstutz & Yates, Wichita, Kans. Production — E. L. Petree, Gulf Oil Co., Houston; Charles H. Hudson, Magnolia Petroleum Co., Dallas; Eldon N. Dunlap, The California Co., Denver; and Wallace W. Wilson, Continental Oil Co., Ponca City, Okla. Natural Gas — C. W. Binckley, Phillips Petroleum Co., Bartlesville, Okla.; Herman A. Otto, Tennessee Gas Transmission, Houston; and A. L. Vitter, Jr., The California Co., New Orleans.

Mallon Will Speak At Branch Luncheon

H. N. Mallon, president of Dresser Industries, will be the speaker at the Fall Meeting Welcoming Luncheon to be held at 12:30 p.m., Oct. 19, in Dallas, Hotel Adolphus Roof Garden.

Topic of his address will be "The Petroleum Engineer's Dream — Ideas to Realities." He will pay tribute to the engineering profession and to AIME engineers in particular. He will elaborate on better methods for converting the ideas of petroleum engineers into realities and discuss the benefits derived therefrom to oil companies and the oil industry.

H. N. Mallon

Well-Rounded Program Ready For Ladies

Of all Petroleum Branch, AIME, Fall Meeting cities, perhaps Dallas is the most alluring as far as the ladies are concerned. As one of the fashion and pleasure centers of the Southwest, the city wastes little time in showing visitors its most glamorous sides.

The industrious members of the Ladies' Activities Committee for this year's gathering, headed by its Chairman, Mrs. Don J. Shaw, have a program lined up that is bound to please.

There will be a milk punch at the Petroleum Engineers Club Monday morning at 9:30, followed by breakfast. From then on you are free to shop, tour, or rest until 7 p.m., when everyone will enjoy cocktails and a buffet supper at the Brook Hollow Golf Club, with DeGolyer and MacNaughton as hosts.

Tuesday noon you will be entertained at the Baker Hotel's Mural Room with a luncheon, and you will see the latest styles that Neiman-Marcus has to offer.

At 7 p.m. that evening, wives will join their husbands for cocktails at the Petroleum Club, compliments of Bradley, Oliver & Associates and Core Laboratories. From there you will go to the Crystal Ballroom of the Baker for delicious food, the famous music of Freddie Martin and his orchestra, and favors for the ladies. This is the annual Petroleum Branch dinner dance, and dress is optional.

Added Fall Meeting excitement is the fact that this year's meeting coincides with the State Fair of Texas, featuring the Ethel Merman Show. Wednesday morning at 11, you will be provided bus transportation from the Baker Hotel to the fair grounds to view one of the most interesting panoramas that Dallas has to offer. You will return to your hotel at 2 p.m., where you can nap if you like until almost 7, when you are expected at the Security Engineering plant for cocktails and Texas' own specialty — barbecue — courtesy of Dresser Industries, Inc.

Pacific Petroleum Chapter

Fall Meeting

October 1, 2, 1953

Ambassador Hotel

Los Angeles, California

F. L. Wadsworth
General Petroleum
Chair., Pac. Pet. Chapter

Morton T. Higgs
Lane-Wells
General Chairman

H. M. Stanier
Sunray Oil Corp.
Luncheon

W. E. Woodruff
Technical Services Co.
Exhibits

C. C. Liedholm
Signal Oil & Gas Co.
Program

J. Shannon Baker
Lane-Wells
Chapter Sec.-Treas.

W. R. Wardner, Jr.
C.C.C.O.P.
Arrangements

Thursday, October 1

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Gold Room.

9:00 a.m. — TECHNICAL SESSION — Ambassador Theater.

Presiding: Henry Abadie and Murray Putnam

337-G *Oil Base Emulsion Drilling Fluids, Their History and a Laboratory Evaluation of Their Characteristics*, by CHARLES WRIGHT, Oil Well Research.

338-G *Performance of Upper Terminal Zone, Fault Block III, Wilmington Field*, by GEORGE AUGUST and STUART N. DAVIDSON, Long Beach Harbor Department.

329-G *A Description and Analysis of an Efficient Continuous Flow Gas Lift Installation*, by A. F. BERTUZZI, J. K. WELCHON, F. H. POETTMANN of Phillips Petroleum Company.

12 Noon — PETROLEUM CHAPTER LUNCHEON — Ambassador Patio

Presiding: Morton T. Higgs

Speaker: Claude R. Hocott, Chairman, Petroleum Branch.

2:00 p.m. — DIRECTIONAL DRILLING FORUM — Ambassador Theater.

Presiding: H. M. Stanier

Panel Members: Gordon Jackson, Moderator; D. S. Johnston; J. T. Ledbetter; Carl Vogelsang; Leonard Graves; E. M. Benson.

Friday, October 2

8:00 a.m. to 5:00 p.m. — REGISTRATION AND EXHIBITS — Gold Room.

9:00 a.m. — TECHNICAL SESSION — Ambassador Theater.

Presiding: Carrol M. Beeson and Loy Charter

311-G *Contribution to Electric Log Interpretation in Shaly Sands*, by A. POUPON, M. E. LOY, and M. P. TIXIER of Schlumberger Well Surveying Corp.

336-G *Improved Hydraulic Rodless Pump Performance Through Use of Electrical Sediment Separator*, by R. E. PHELAN, Shell Oil Co.

339-G *Under Saturation During Repressuring and Super Saturation During Flow of Oil to Wells*, by RALPH HIGGINS, U. S. Bureau of Mines.

12 Noon — SOUTHERN CALIFORNIA SECTION LUNCHEON — Cocoanut Grove.

Speaker: Dr. R. E. Vivian, University of Southern California.

2:00 p.m. — TECHNICAL SESSION — Ambassador Theater.

Presiding: John E. Sherborne and G. B. Shea

328-G *Method for Calculation Recovery of Light Hydrocarbons by Gas Cycling Semi-Depleted Dark Oil Sands*, by C. N. SIMM, California Research.

3:00 p.m. — Ambassador Theater.

Speaker: Dr. Cyril Stanley Smith, Director of the Institute for the Study of Metals, University of Chicago.

8:00 p.m. — ANNUAL BANQUET AND DANCE — Embassy Room, Ambassador Hotel.

Exhibitors' Guide

Exhibitor	Booth No.
Baker Oil Tools, Inc.	22
Byron Jackson Service, Inc.	20
B & W, Inc.	14
Core Laboratories, Inc.	23
Encyclopedia Britanica	16
Ford Alexander Corp.	17
Halliburton Oil Well Cementing Co.	18
Lane-Wells Co.	1
Martin-Decker Corp.	21
McCullough Tool Co.	15
Rapid Blue Print	2
Schlumberger Well Surveying Corp.	13

ABSTRACTS

OF PAPERS TO BE PRESENTED AT DALLAS AND LOS ANGELES

278-G
History and Performance of the Coldwater Oil Field, Michigan

C. R. Criss and R. L. McCormick, Sohio Petroleum Co., Tulsa, Oklahoma

This paper summarizes the development and performance of the Coldwater Oil Field, Isabella County, Michigan. Production is obtained at a depth of 3,750 ft from a dolomite reservoir, which is probably both Rogers City and Dundee. There appears to be no barrier to vertical fluid movement between the Rogers City and Dundee, and both formations are believed to have a common original oil-water contact. No wells are open to production at the level of the Dundee.

The discovery of the field in 1944 was followed by the drilling of 81 producing wells and nine dry holes. By the end of 1952, the field had produced 12,763,000 bbl of oil, at which time 69 active wells were producing 3600 B/D oil and 21,000 B/D water.

The reservoir has an effective natural water drive, and bottom-hole pressure has declined 75 psi from an original of 1,453 psi. Oil is undersaturated at reservoir conditions with a solution GOR of 512 cu ft/bbl and a saturation pressure of 1,190 psi.

280-G
Pressure Maintenance by Gas Injection in the Brookhaven Field, Mississippi

J. B. Justus, R. W. Cassingham, C. R. Blomberg, and W. H. Ashby, Jr., The California Co.

The Brookhaven Field is a sandstone reservoir, of erratic deposition with several faults, having an approximate subsea depth of 9,800 ft. A large variation in permeability exists with a weighted average being 256 md. Estimated average interstitial water saturation is 45 per cent. The under-saturated reservoir fluid exhibits marked differences in physical properties with measured saturation pressures ranging from 733 to 2,555 psi. At the time gas injection was commenced, the reservoir pressure had fallen to nearly half of the original pressure when only 4.5 per cent of the original oil in place had been produced. The reservoir pressure has since been maintained at approximately 2,750 psig and cumulative production to date is 17 per cent of original oil in place. An analysis of field performance during gas injection is presented in detail.

281-G
Metallurgical Aspects of Sucker Rods and Their Oil Well Performance

Frederick J. Radd, Continental Oil Co.

The mechanisms of corrosion and corrosion fatigue damages to sucker rods have been examined from a fundamental electrochemical viewpoint, and the relationships of sucker rod microstructures to these damaging effects defined. The common corrosive agents in crude oil production and storage have been correlated with the types of attacks that they cause. The variations of fatigue strength with alloy content, surface preparation, and stress ranges have been analyzed and representative microstructures, graphs, and examples presented to illustrate these points. Recommendations for selection and use of sucker rods have been made for the petroleum engineer so that an efficient working life may be obtained under a wide variety of service conditions.

282-G
A New Gas Lift System

R. P. Vincent and L. B. Wilder, Stanolind Oil and Gas Co.

A system of gas lift involving the use of two strings of tubing side by side (1¼-in in 5-in OD casing and 1¼-in or 2-in in 7-in casing) is described. Gas is injected through one string and produced through the other. Solid rubber balls, suitably collected and injected at the surface, interspaced between slugs of gas, act as a solid interface in lifting the oil through the second string of tubing. The system has all of its important working parts at the surface or readily retrievable without pulling tubing. The system is such that regardless of the nature of oil, gas, and/or water handled, volumetric efficiency is 100 per cent. It will operate at any depth to which tubing can be run. It has been designed particularly for low fluid level, deep wells, but will perform equally efficiently in shallow wells. The input gas lift ratio never need exceed 200 to 250 cu ft per bbl per 1,000 ft of depth. The system lends itself by its nature to the cycling of corrosion inhibitors, and paraffin is continuously removed. Rates of production, depending on each individual well, can be controlled entirely by the use of surface timing devices. Field test results are reported.

283-G
Automatic Lease Operations Weeks Island Field, Louisiana

T. P. Northern, Gulf Oil Corp.

The report was prepared upon completion of automatic lease operations on Gulf's Provost Cyr Unit Lease, Weeks Island, La. It is the first in a series of such installations for Bay Fields and possible offshore production. The report was submitted to management for the purpose of aiding in the elimination of as many problems as possible prior to initiating such work in some of the larger fields which have similar operating conditions. Requirements of equipment with emphasis on tank switching and well flow control, are brought out. The selection of equipment for all phases of operation, such as automatic tank battery installations, control panel equipment, electrical distribution system, and well flow control valves, both electrical and pneumatic, are other topics discussed.

284-G
Pump Volumetric Efficiency — A Study of the Effects of Pumping Variables

C. A. Connally, C. R. Sandberg, and N. Stein, Magnolia Petroleum Co.

This paper describes the results of volumetric efficiency tests on oil well pumps handling gas-oil mixtures. The work was performed on a large scale, above ground, unit wherein test conditions could be accurately controlled and measured. The main variables studied were gas/oil ratio (including gas from solution and free gas mixed with oil), pump compression ratio, pump stroke length, pump speed, and clearance volume between the valves at their closest approach. Results are presented for two different pumps and for the use of oils of two viscosities. Relatively small amounts of gas entering the pump resulted in large decreases in volumetric efficiency. Under conditions where the pump was operating at reduced efficiency because of the presence of gas, it was found that variation of the clearance volume between standing and traveling valves had a considerable effect on pump efficiency level. This effect of the valve clearance volume was found to be significantly altered by the viscosity of the oil used in the test. The effects on pump efficiency of the other variables studied were found to be relatively small over the range of conditions utilized.

288-G
An Inexpensive Mud for Deep Wells

H. F. Coffer, Continental Oil Co.

This paper summarizes the results of laboratory and field work conducted during the development of a new inexpensive drilling mud which can be used to replace conventional lime red muds. This new mud has all of the desirable drilling characteristics of a lime red mud, including resistance to gypsum, anhydride, cement, and salt contamination. Its resistivity can be easily controlled between 0.2 and 2.50 ohmmeters. In addition, the mud does not jell at high temperature. A sample after being heated six months at 350° F had a lower viscosity than when originally mixed. In the first field test of the new mud in a 10,600-ft Louisiana well, mud costs were reduced from an average of $9,000 to $4,400. The daily treatment costs for a 1,600-bbl system was only $33, indicating that even greater savings will result when using the mud for drilling deeper wells.

289-G
Filtration from Mud During Drilling

C. K. Ferguson and J. A. Klotz, California Research Corp.

This paper describes experimental investigations conducted at the California Research Corporation's model oil well. The first part describes filter loss from several drilling muds through bore hole walls during mud circulation and drill string rotation. The effect of mud properties and drill string rotation with mud circulation is described. Filtration from a bore hole full of drilling mud, not circulating, but under pressure for extended time periods, is also discussed.

The second part describes filter loss to permeable formations from beneath a drilling bit where filter cake has no opportunity to develope appreciable thickness. If potential flow theory is applied to predict filtrate invasion from this hole bottom, large invasions are calculated. But model well experimentation shows that filtrate invasion from the hole bottom is controlled by mud particles that penetrate the formation ahead of the bit. This experimentation provides data to estimate the effect of mud particle penetration on fluid loss to formation.

The third part presents an estimate of mud filtration during drilling of a well.

290-G
The Mechanical Treatment of Weighted Drilling Muds

Roy A. Bobo and R. S. Hoch, Phillips Petroleum Co.

Maintenance of desirable plastic flow properties of weighted drilling muds may be greatly simplified by use of centrifugal classification to control the drilled solids content. The new application of a decanting type centrifuge to separate and reject the low density solids from the weighting material results in a drilling mud of greatly improved quality with lower values of yield and rigidity. Its practicality and economy has been proved in field operation. The degree of separation of light and heavy solids is not limited by the machine but by the particle size distribution of the solids in the mud. Removal of the low density component of drilling mud that makes chemical treatment necessary makes possible a marked reduction in chemicals. The main uses of the centrifugal process are the treatment of muds while drilling, the reclaiming of discarded muds, cleaning up of workover muds, and the reduction in lime content of mud for completion.

291-G
Drilling Mud Control in the Southwest Louisiana Coastal Area

C. R. Claus and J. A. Standish
Magnolia Petroleum Co.

Since March, 1945, the Magnolia Petroleum Co. has drilled 41 wells in Southwest Coastal Louisiana. All wells were drilled within a comparatively small radius, but the area provides a large variety of problems. The deepest well drilled was 12,508 ft, and the total depth averaged 10,765 ft. Over this period types of mud handled were phosphate, red lime (late conversion), red lime starch (early conversion), red lime starch oil emulsion, precision controlled low alkalinity-low lime content, and gel muds for completion purposes. Improvement has been obtained in effecting some or all of the following: more rapid penetration, reduction in drilling hazards, better evaluation of cores and logs, and better completions. The geological sequence of zones penetrated range from recent sediments at the grass roots through the Frio section. Anticipation of high-pressure zones and incompetent formations entails precision control of drilling mud weights, and the unconsolidated nature of the various zones requires constant attention to the filtrate, viscosity, and gel strength values. In the Chalkley Field particularly, this combination of problems exists where the formation pressures and overburden weight density values are in very close proximity. Design of casing and drilling mud programs must be modified to fit each well.

296-G
A Method for Determination of Average Pressure in a Bounded Reservoir

C. S. Matthews, Shell Development Co.; F. Brons, Shell Oil Co.; and P. Hazebroek, The Hague

A method has been developed for calculating the average pressure in a bounded reservoir. The reservoir is first divided into the individual drainage volumes of each well, by using the criterion that at steady state each individual drainage volume is proportional to a well's production rate. The average pressure in each drainage volume is then calculated by a method developed in the report. By volumetrically averaging these individual drainage volume pressures, the average pressure in the entire reservoir is obtained. To calculate the average pressure in each drainage volume, a correction is applied to the ordinary extrapolated pressure, *i.e.*, the pressure obtained by extrapolating to infinite time the linear portion of the graph of closed-in pressure *vs* log $[\triangle t/(t+\triangle t)]$, where $\triangle t$ is the closed-in time and t the production time. The correction, which is a function of the production time, is presented in graphical form for different shapes of the drainage area (horizontal cross section of the drainage volume).

297-G
Viscosity of Hydrocarbon Gases Under Pressure

David B. Burrows, Continental Oil Co.; and
Riki Kobayashi, Rice Institute

It is the purpose of this paper to present a method for calculating the gas viscosities of complex hydrocarbon mixtures at reservoir temperatures and pressures. This method has been developed from data obtained in the literature and is based primarily on the following properties: experimental gas gravity, molecular weight of gas, pseudo critical temperatures and pressures, viscosity of gas at 1 atmosphere.

From these data the gas viscosity at the desired pressure and temperature can be calculated. The atmospheric gravity of the evolved gas at test pressure and temperature is, therefore, the only experimental value necessary to determine the desired gas viscosity. This correlation provides a means of calculating the gas viscosities of naturally occurring reservoir mixtures to within 5 per cent of their actual value.

298-G
Effect of Pressure and Temperature on Oil-Water Interfacial Tensions for a Series of Hydrocarbons

M. E. Hassan, R. F. Nielsen, and J. C. Calhoun, Jr.,
The Pennsylvania State College

An apparatus was constructed for the measurement of interfacial tensions over a range of temperatures and pressures, utilizing the pendent drop method, and resembling in construction similar apparatus recently described in the literature and in use in some petroleum research laboratories. The interfacial tensions of benzene, propane, n-butane, n-pentane, n-hexane, n-octane, and isooctane against water were measured at temperatures ranging from 26° to 82°C and at pressures ranging from 1 to 204 atmospheres. Values of interfacial tensions for the benzene-water system and their variations with temperature and pressure are generally in good agreement with values of previous investigations. The data in all cases showed a slight decrease of interfacial tension with pressure at constant temperature in the range studied. The effect of pressure became less as the pressure was increased, with an indication of a reversal of the effect at higher pressures. There was a decrease of interfacial tension with temperature at constant pressure in all cases. This rate of decrease became greater the higher the temperature.

300-G
Plugging Off Water in Fractured Formations

G. C. Howard and P. P. Scott, Jr., Stanolind Oil and Gas Co.

A field remedial procedure utilizing a kerosene-cement slurry as a water plug-off agent in fractured formations has been developed. This method, evaluated both in the laboratory and in 10 field tests, has proven to be capable of effectively shutting off water without impairing oil production. Success is due to the fact that the cement, when placed, has a relatively high permeability to oil and permeability decreasing to zero after contact with water. This characteristic permits the effective removal of the barrier from any oil-producing zone by acidizing.

301-G
Electric Logging in Thin Beds

Leendert de Witte, Continental Oil Co.

Quantitative interpretation of resistivity curves in beds thinner than 20 ft is usually made unreliable or impossible by adjacent bed effects and boundary anomalies. To surmount these difficulties, combinations of focusing logs such as the MicroLaterolog, various types of modified laterologs, and pseudo laterologs have been investigated. Using departure curve data computed on the Whirlwind I computer at M.I.T. an optimum combination of these devices has been determined. For this combination, a system of direct reading simplified departure curves has been prepared. These departure curves are plotted for constant values of the ratio of invaded zone resistivity over mud resistivity, assuming

that the invaded zone resistivity can be obtained from the Micro-Laterolog with mud cake corrections from the MicroLog. The ordinate contains the apparent resistivity of the modified laterolog and the abscissa the apparent resistivity of the modified pseudo laterolog. Two families of curves give directly the values of true resistivity and invasion diameter for any measured pair of the above apparent resistivities.

302-G
An Experimental Investigation of the S. P. and Resistivity Phenomena in Dirty Sands

M. R. J. Wyllie and P. F. Southwick
Gulf Research & Development Co.

The importance of the so-called "dirty sand" or "conductive solids" problem in electric log interpretation was first stressed in a paper presented in 1949. Since that time the problem has been generally recognized as a most serious one. Several research papers bearing on the theory of the effects of clay contaminants on reservoir rock resistivities have appeared. These papers, while contributing to the theory of the problem, have not offered any practical solution. In the present paper, an experimental investigation has been made of the effects of ion-exchange materials on the electrical properties of natural and synthetic porous media. The method used to make synthetic dirty sands is entirely novel and has proved a most valuable guide to a better understanding of the properties of dirty sands generally. The effects of ion-exchange materials on both the resistivity and SP logs have been examined. From the data obtained it has been possible to formulate a simple, practical method whereby electrical logs of dirty sands can be interpreted. The method is in all essentials identical with that presently in use for interpreting clean sands.

303-G
Red Fish Bay Field, Nueces County, Texas

O. J. Shirley and D. R. Dunham, Shell Oil Co.

The Red Fish Bay structure is a semi-circular closure in the upthrown block of a 400 ft down-to-the coast fault and is one of the numerous coastline structures believed directly attributable to deep seated salt movement. The productive limits of the field encompass approximately 5,800 acres, with a maximum closure of 175 ft. The discovery of the field resulted from the drilling of Shell Oil Co. *et al*-State Tract 342 No. 1 which was completed in August, 1950, as a Marginulina Frio (Zone 6) gas well. Subsequent exploitation has established commercial hydrocarbon accumulations in one Anahuac sand and eleven Marg Frio sands between the depths of 7,000 ft and 9,000 ft. Of these zones, five are gas bearing and the remainder contain oil.

307-G
A Study of Displacements in Microscopic Capillaries

Charles C. Templeton, Shell Development Co.

Techniques have been devised or improved for the observation of air-liquid and liquid-liquid displacements in uniform Pyrex capillaries with diameters as small as 4 microns. Qualitative descriptions of the behavior of moving interfaces are presented. Quantitative observation of a large number of air-liquid displacements with zero contact angle, indicates the adequacy of a model based on Poiseuille's law, and the independence of capillary pressure and interfacial velocity. For the displacement of a very viscous oil by water in a capillary initially filled with water, flow is faster than predicted by the above model.

308-G
Displacement Experiments in a Consolidated Porous System

J. S. Levine, Shell Development Co.

A series of four displacement experiments has been run in a large alundum core. Flow potential distribution in each liquid phase was measured continuously through oil-wet and water-wet capillary barriers, using a null-point pressure balance, and saturation distribution was determined from electrical resistivity measurements. A method has been devised for calculating the effective (and relative) permeability to each phase at any time and at any point in the flow system for the transient displacement process. Relative permeability points have been calculated and average curves drawn for oil displacing water and water displacing oil. The values of dynamic capillary pressure have also been determined. Data have been substituted into the generalized Buckley-Leverett fractional flow equation and a comparison between actual and theoretical breakthrough recoveries is shown.

309-G
Oil Production After Breakthrough As Influenced by Mobility Ratio

A. B. Dyes, B. H. Caudle, R. A. Erickson,
The Atlantic Refining Co.

The study of the influence of fluid mobilities on the sweepout pattern resulting from the injection of gas or water has been extended to cover the production period which follows breakthrough of the injected material. Mobility ratios over the range common in field operaions (0.1 to 17) were studied for several pattern floods (five-spot, staggered and direct line drive). The experimental data required for these studies were obtained by the use of the X-ray shadowgraph technique using miscible oil phases of different viscosities in porous plate models of a reservoir element. From the shadowgraph pictures obtained before and after breakthrough of the injected fluid, flowing ratios at the producing well and cumulative volumes injected were calculated.—The method for applying such data in predicting field behavior is illustrated for the five-spot flood.—For this case a range of mobility ratios of 0.1 to 8.0 results in: (1) nearly complete (85 per cent to 100 per cent) sweepout patterns efficiencies at abandonment conditions, (2) production after breakthrough being responsible for as much as 50 per cent of the total recovery at the lower mobility ratios and (3) up to a two-fold variation in the operating life of the reservoir.

310-G
Interrelation of Resistivity and Potential of Shaly Reservoir Rocks

F. M. Perkins, Jr., H. R. Brannon, Jr., and W. O. Winsauer,
Humble Oil and Refining Co.

The lowering of the resistivity factor with decrease of concentration of the saturating electrolyte in shaly reservoir rocks is related to the adsorptive properties of the rock. This adsorptive property of a rock is found to be a function of the electrolyte concentration and may be described by a Freundlich adsorption isotherm. Likewise, the Mounce potential is influenced by the same adsorptive properties. Because of the concentration difference which exists across a rock which exhibits a Mounce potential, the dependence of adsorption upon concentration must be considered. By the use of equations which recognize this, the Mounce potential may be predicted from resistivity factor data. Experimental results with shaly sands from different formations are included to corroborate the predicted interrelation of the resistivity factor and Mounce potential.

311-G
A Contribution to Electric Log Interpretation in Shaly Sands

A. Poupon, M. E. Loy, and M. P. Tixier,
Schlumberger Well Surveying Corp.

An approach towards electric log interpretation in shaly sands is presented. This approach is based partly on theoretical and experimental data available in the literature, partly on observations made on logs. A simple tentative method of qualitative interpretation is described, which should apply to sands containing either laminated shales (shaly sands of the sandwich type) or dispersed shale (dirty sands), or both. The application of this method only requires information provided by the electric logs. An extension of the method to quantitative analysis is suggested, which makes use of reasonable assumptions on some of the factors involved. Nomographic charts are provided to facilitate the necessary computations. The conditions necessary for a reliable application of the method are discussed. Field examples illustrate the paper.

312-G
A Ten-pound Cement Slurry for Oil Wells

Roscoe C. Clark., Jr., Continental Oil Co.

In many oil producing areas considerable difficulty is encountered in casing cementing operations in obtaining a satisfactory "fill-up." It is generally accepted that the reason for this difficulty is that the cement slurries in use are of sufficiently high density and that zones of lost circulation are created, into which the cement is lost. Bentonite and expanded perlite are currently in use as additives to cement slurries for the purpose of decreasing slurry weights. These additives have been effective in many cases; however, in other cases cement "fill-ups" are still difficult to obtain, and in others cement strength development has been seriously impaired

by the addition of too much bentonite or expanded perlite. At present, cement slurry weights cannot be decreased below 12 lbs. per gal (under bottom hole conditions) without loss in desired strength. A new additive has been developed which can be used to safely reduce cement slurry weights to as low as 10 lbs per gal.

313-G
A Simplified Cementing Technique for Recompletion Operations

T. A. Huber, G. H. Tausch, and J. R. Dublin, III,
Humble Oil and Refining Co.

Simplified equipment and techniques have been developed to permit cementing a completion interval in a well and recompleting higher, lower, or at the same depth in such a manner as to eliminate the need for a conventional drilling or workover rig, eliminate mud and other cement contaminants which have long interfered with ideal cementing, eliminate need for drilling out cement, provide a more satisfactory recompletion, and provide a more economical recompletion. This technique involves the use of a small-diameter, lightweight, tubing extension which is run on a wireline and set in a landing nipple previously installed in the tubing string. Low squeeze pressure and small cement volumes, with their attendant cost reduction, are successfully used when wells are completed and reworked with salt water or other penetrating fluids.

314-G
The Effect of Surface- and Interfacial-Tensions on the Recovery of Oil by Water Flooding

Harvey T. Kennedy and Erasmo T. Guerrero,
Texas A&M College

In this investigation, the effect of six different commercial surface-active chemicals on oil recovery by water-flooding Woodbine sand was determined. Preliminary experiments indicated that all of the chemicals were highly adsorbed on the sand, and that if the chemicals were merely added to the flood water prior to flooding, they would not be at the flood front when the oil was actually displaced. To remedy this condition, the sand and its contents were saturated with the surface-active chemical before the flooding process was carried out. The results, thus, should duplicate the effect of a chemical which was not adsorbed on the sand. Tests were made above the bubble-point and at two pressures substantially below the bubble-point. Tests covered a range of water-oil interfacial tensions from .4 to 22 dynes per centimeter and a range of gas-water surface tensions of 32 to 58 dynes per centimeter, at reservoir conditions. No benefit was found to result from the addition of the chemicals, but a slight adverse effect, due perhaps to the property some of the chemicals to cause oil-wetting of the sand, was noted.

315-G
Water Flooding Facilities, Salem Unit, Marion County, Illinois

Rex L. Livingston, The Texas Co.

The Lake Centralia—Salem Oil Field, Marion County, Ill., was unitized for the water flooding of five pay horizons. It is estimated that the unitized field area of 8,800 acres will require the ultimate injection of approximately 1,680,000,000 bbl of water during a 20-year flood. Facilities have been designed to permit the treatment and injection of 350,000 bbls of water daily from one central plant. A pressure distribution system, consisting of 71 miles of pipe from 2-in to 14-in size, has been installed to supply this water at pressures up to 1,500 psi into some 400 injection wells. More than 38 miles of corrosion resistant pipe lines from 2-in to 16-in in size have been installed to handle the estimated peak oil and water production of the field into several consolidated tank batteries. The author discusses briefly the initial installation of these facilities to accommodate the secondary recovery operations and some of the economic aspects affecting certain phases of design, equipment, and construction.

316-G
Twelve Years of Gas Injection in a Frio Sand

B. T. Millikan, Jr., Continental Oil Co.

Increased oil recovery and sustained rate of production have been obtained by injection of 75 per cent of the produced gas in the Rincon D-5 reservoir. The gas injection program was inaugurated in 1941 when less than 1 per cent of the oil had been produced. The gas has been returned thru one input well in the gas cap. The oil zone covers an area of 1,800 acres and the gas cap 400 acres. Injection operations are still in progress and 700 B/D of oil is currently being produced. Oil, gas, and water production and gas injection records, core analyses, relative permeability measurements and a reservoir fluid analysis are available. Bottom hole pressures have been taken at six-month intervals for each of the 35 producing wells since initial completions. Cross-sections, a structure contour map, and an isopachous map are used to describe the geological characteristics of the reservoir. Performance and producing status of individual wells and the reservoir as a whole are analyzed with special reference to the effect of discrepancies in field data and field operations on calculations by material balance.

317-G
Reservoir Fracturing, A Method of Oil Recovery from Extremely Low Permeability Formations

L. E. Wilsey and W. G. Bearden, Stanolind Oil and Gas Co.

The report presents results of an analysis of the effect of fracturing on initial flow rates and on ultimate recoveries from oil reservoirs. Field production information is shown which supports the analytical work. The report presents a new concept for recoveries from extremely tight formations by creation of large fractures. Generally speaking, fracture treatments have been such that fractures of only a few feet resulted and the production rate increase resulted from breaking through a narrow damaged zone of reduced permeability adjacent to the well bore. It has been the belief that in fracturing wells in which there is no zone of damaged permeability adjacent to the well bore, the maximum production rate increase would be in the order of two- to four-fold. Hence, it has been concluded that fracture treatment of uniformly low permeability formations could meet with small success. This paper shows analytically that fracture treatments much larger than generally employed can yield commercial producing rates even in formations having permeability as low as 0.1 md. Large fracture treatments, even at this low permeability range, can yield oil recoveries and production rates approaching those of high permeability formations.

318-G
The Mechanics of Formation Fracture Induction and Extension

W. J. McGuire, Jr., Eugene Harrison, W. F. Kieschnick, Jr.,
The Atlantic Refining Co.

This paper concerns the induction and extension of fractures into rock formations as involved in drilling, completing, and production stimulating operations on wells. Conclusions concerning formation breakdown are derived from (1) a review and extension of published analyses relating to mechanical theories of rock stress and the state of stress in the earth's crust and, (2) a correlation of field data from fracturing operations. Conclusions concerning the mechanics of fracture extension, which indicate the relationship between fracture dimensions and rock properties, depth, and volume of injected fluid, are tentative and largely establish limits of relationships. These conclusions are derived from stress calculations, limited field data, and laboratory experimental studies. The experimental work involves the study of the stresses at the fracture boundaries and the geometry of pressurized fractures by means of photoelastic modeling methods.

319-G
Effectiveness of Gun Perforating

T. O. Allen and J. H. Atterbury, Jr.,
Humble Oil and Refining Co.

Laboratory and field tests during the past five years indicated considerable variation in the penetrating power of commercially available gun perforators. Many of the guns which achieved inadequate penetration in these tests have since been improved. However, recent productivity tests indicated the possibility of inadequate penetration or, at least, ineffective penetration in some wells. Laboratory experiments under simulated well conditions have demonstrated considerable plugging of the perforations, apparently as a result of factors associated with the shooting process and/or the drilling mud in the well at the time of perforating. The restriction to flow per unit of hole depth caused by this plugging appears to be greater for jet perforators than for bullet guns of comparable diameter; however, because of the greater depth of penetration obtained with the jet guns, the total flow rates appear to be approximately equal. Limited testing with an experimental shaped charge suggests that less shot hole restriction and greater flow rates may result from larger-diameter perforations or other factors related to charge design.

320-G
Practical Aspects of Gravel Packing

C. J. Rodgers, Gulf Oil Corp.

The present day success of gravel packs to prevent or retard the migration of unconsolidated sands into the well bore is due to: (1) the use of a saline or non-aqueous, nonsolids drill fluid, (2) proper preparation of the well bore prior to gravel packing, and (3) pressure placement of the gravel. The experience gained from the "pressure pack" method of gravel packing indicates that sand free, fluid production can be maintained for a length of time sufficient to make the operation economically attractive. Data pertaining to the first fifteen wells so completed by Gulf indicate that for each dollar spent to effect the completion, there will be a return of more than $2.92. The pressure pack technique of gravel packing is essentially the placing of gravel in and adjacent to the producing formations. This is done with fluid pressure and by the use of a drill fluid that will permit partial or complete loss of returns to the formation during placement. This technique was first intentionally used by Gulf in May, 1950, and since that time has been applied in more than 90 wells.

321-G
The Combustion Gas Turbine — Historical Development and Present Day Applications to Natural Gas Pipelines

Tracy S. Park, Jr., Tennessee Gas Transmission Co.

In 1949 the first gas turbine-driven centrifugal compressor was installed on a natural gas pipeline, and has proven extremely successful in reliability of service. This machine represents the least complicated of all gas turbine power plants, in that it is a one-shaft single-compressor, single turbine, non-regenerative unit. It cannot be considered competitive with conventional reciprocating gas engines for general pipeline service, due to its narrow range of load maintenance at maximum efficiency. The gas turbine plant which is presently offered for a maximum of flexibility on pipelines, is a two-shaft, single-compressor, two-turbine, regenerative unit. The standard of the gas transmission industry in the past has been the conventional gas engine. It necessarily follows that the parameters of specific fuel consumption, flexibility in operation, maintenance and first cost of material and installation, of the gas turbine-centrifugal compressor combination must be compared to the gas engine-reciprocating compressor combination. Insufficient operating hours on the competitive two-shaft gas turbine do not allow an accurate, final appraisal to be made. However, preliminary comparisons of the above-mentioned parameters indicate that the gas turbine driven centrifugal compressor will very likely find increasing application for service on natural gas pipelines.

322-G
Multi-Phase Co-Current Flow of Fluids in Horizontal Pipes

R. L. Huntington, University of Okla.

Three two-phase systems, gas-water, gas-kerosene, and gas-SAE 20 and 40 lube oils have been studied in clear plastic tubing 1-in., 1.5-in., and 2 ft I.D. in 100 ft lengths. Pressure drop data have been obtained on a wide range of ratios and flow rates. Motion pictures have been made in order to establish the various flow patterns. The 16 mm colored motion picture film requires 18 to 20 minutes for presentation and the paper about 20 minutes which precedes the motion picture.

323-G
Design of Two-Phase Gathering Pipe Lines

Ovid Baker, Magnolia Petroleum Co.

With the increasing use of central separator batteries, long lines are required to carry simultaneously oil and gas from some wells to the separator station. Pipelines carrying both gas and liquid hydrocarbons are being used more often in terrain such as deserts, swamps and off-shore installations. Methods for the design of these two-phase pipelines are in the process of development. Most experimental work reported to date covers lines from $\frac{1}{8}$-in. to 2-in. diameter. We have experimented with lines from 4-in. to 10-in. in diameter. The only adequate correlation proposed to date is that of Martinelli, which was based on pipe sizes up to 1-in. in diameter. This correlation predicts higher pressure drops for larger size pipe than we found in our field experiments. Our data are presented together with convenient charts and calculation procedures for the rapid design of two-phase pipelines.

325-G
Estimated Effect of Vertical Fractures on Secondary Recovery

Paul B. Crawford and R. E. Collins, Texas Petroleum Research Commitee

Potentiometric model studies have been made of vertically fractured reservoirs. All fractures originated at the well and extended into the reservoir for various distances. Studies were made to determine the areal sweep efficiencies for line-drive patterns. The areal sweep efficiency for the unfractured system studied was 70.6 per cent. It was found that if the vertical fracture was parallel with the direction of flood, the areal sweep efficiency may be considerably reduced, approaching zero in some instances. If the fracture was at right angles to the direction of flood, the areal sweep efficiency may be greater than that for the unfractured system. The sweep efficiency depends on the length and orientation of the fracture and direction of the flood. It is concluded that considerable effort should be made to determine the nature and direction of fractures before initiating a flooding program. Such information is required if the maximum sweep efficiency is to be obtained and channeling is to be reduced to a minimum.

327-G
Equilibrium Vaporization Ratios for a Reservoir Fluid Containing a High Concentration of Hydrogen Sulfide

Harold Vagtborg, Jr., The Pure Oil Co.

Equilibrium vaporization ratios were obtained for light hydrocarbons, nitrogen, carbon dioxide, and hydrogen sulfide in a reservoir fluid containing 35 mole per cent hydrogen sulfide. The data cover the range from 700 to 2,500 psia at 154°F. The results of this study are compared with results obtained by other investigators on systems containing less hydrogen sulfide. When large amounts of hydrogen sulfide are present, the equilibrium vaporization ratios for ethane and heavier hydrocarbons are greater than the ratios for systems containing little or no hydrogen sulfide. Large amounts of hydrogen sulfide have the reverse effect on the ratios for methane. Routine PVT studies were performed on the reservoir fluid including flash and differential liberations of the dissolved gas. The pressure-volume relationships of the saturated fluid were also determined. It is shown that the use of published correlations on physical properties of reservoir fluids can lead to gross errors when applied to systems containing large amounts of hydrogen sulfide.

328-G
Recovery of Light Hydrocarbons by Gas Cycling A Semi-Depleted Dark Oil Sand

C. N. Simm, California Research Corp.

Results are presented of an experimental and theoretical investigation of the recovery of light hydrocarbons from a semi-depleted dark oil sand by their vaporization into an injected dry gas. A general method of calculating recovery is presented which relates effluent gas composition to well spacing, time and rate of cycling, reservoir hydrocarbon content, pressure and temperature. The proposed equations and methods of application may be used to calculate cycling recovery in any reservoir for which customary material balance data are available. In experiments with sand packs, recovery by dry gas cycling was observed to be a direct function of temperature and an inverse function of pressure. Flow rate of cycling gas had no effect upon recovery at velocities encountered in the field.

329-G
A Description and Analysis of an Efficient Continuous Flow Gas-Lift Installation

A. F. Bertuzzi, J. K. Welchon, and F. H.Poettmann, Phillips Petroleum Co.

A series of gas-lift tests was made which verified conclusions reached from previous studies and which showed that gas-lift performance can be calculated if reasonably accurate data on the producing characteristics of the well are available. The test installation is described. Its essential features consisted of a rate-of-flow controller to regulate the input gas and an auxiliary string of small diameter tubing to conduct the input gas to the point of injection in the eductor tubing. In general, it was shown that for continuous gas-lift operation, injection should be as deep as possible consistent with available gas pressure and rate of production desired. Calculated curves are presented which completely characterize the gas-lift performance of the well tested.

330-G
The Isochronal Performance of Determining The Flow Characteristics of Gas Wells

M. H. Cullender, Phillips Petroleum Co.

The pressure drop resulting from the production of gas from a particular gas well is controlled by the rate of flow and the distance to which the radius of drainage has receded from the well bore. Experimental data on various gas wells are presented to show that the recession of the radius of drainage is a function of time and, for all practical purposes, is independent of the rate of flow. Data are also presented to show that the conventional method of obtaining back-pressure data often results in the development of complex pressure gradients within the drainage area which obscure the true performance characteristics of the well. Flow data obtained at constant time intervals from shut-in condition are presented to show that the slope of the performance curves of a gas well is established within minutes after a well is opened and is independent of the drainage area and, therefore, independent of time.

331-G
Performance of A Water Drive Field Torchlight Tensleep Reservoir, Wyoming

F. H. Calloway and F. M. Stewart, Stanolind Oil and Gas Co.

The Torchlight Tensleep reservoir is a small, well defined sandstone reservoir under an active water drive. Because pressure has never decreased to the bubble point, water production to date has been negligible, and the reservoir is small and well defined, it is readily adaptable to analyzing performance by the use of the electric analyzer and various mathematical methods of computation. Predictions made can be verified or disproved in a short time. Use of the various methods of computing oil-in-place and predicting performance are compared for this reservoir together with discussion as to the limitations and accuracy of each method. The concept of a decreasing reservoir pressure and producing rate due to the increasing resistance to the flow of water through the invaded zone as the reservoir is depleted is discussed.

332-G
Dimensionally Scaled Experiments and the Theories on the Water-Drive Process

G. A. Croes and N. Schwarz
De Bataafsche Petroleum Maatschappij, The Hague

The model displacement experiments to measure the efficiency of the water-drive process, started by Engelberts and Klinkenberg, have been extended. A detailed picture has been obtained of the influence of the oil/water viscosity ratio. The results are represented in the form of a diagram from which both the oil recovery and the water/oil ratio can be easily read as a function of total (oil plus water) production for all values of the viscosity ratio in the range from 1 to 500.

These results are compared with the two existing theories on water flooding, *viz.* that of Buckley and Leverett and that of Dietz. It is demonstrated that the two theories would become equivalent if the relative permeabilities to oil and water were linear functions of the saturation.

336-G
Improved Hydraulic Rodless Pump Performance Through Use of Electrical Sediment Separator

R. E. Phelan, Shell Oil Co.

One of the difficulties encountered in Kobe pumping operations is the problem of providing clean power oil. Past experience has indicated that the performance of Kobe pumps can be improved by reducing the solids content of the power oil by installing additional tankage. An effort was made to determine if any equipment was available which could be used to further improve the operations.

An electrical sediment separator was procured from the Petrolite Corporation and installed at the Ten Section field. The unit operated at a rate of 1,000 B/D for nine months. Results from this test have shown the engine-end efficiency decline of the five pumps was reduced from 12 per cent per month to 1 per cent per month. The well pulling and pump repair cost for the five wells would be reduced about $3,000 per year.

337-G
Oil Base Emulsion Drilling Fluids, Their History and A Laboratory Evaluation of Their Characteristcs

Charles C. Wright, Oilwell Research

Oil base emulsion drilling and completion fluids have been used in over 400 wells in the past three years. Superior completions are claimed for their use and they have replaced costlier completion fluids in many fields. Besides yielding high completion and long time productivities, the oil base emulsion fluids are inert to the usual contaminants and can be compounded to low mud weights when desired. Improved oil base emulsion muds are now available which suspend cuttings, can be weighted, and which do not cause hydratable material to swell. Shale hydration tests in oil base emulsion muds are described, which are a necessary consideration in their selection. These new completion and drilling fluids are defined, described, and their history is related.

338-G
Upper Terminal Zone, Block III Pool, Wilmington Oil Field

George August, Long Beach Oil Development

This paper presents a summary of the results of a study of the Upper Terminal Zone, Fault Block III reservoir of the Wilmington Oil Field, Los Angeles County, California. While the field as a whole has been discussed in the literature in past years, the data here are of special interest because of the emphasis on reservoir conditions. First production was obtained in January, 1938, with development being essentially completed by April, 1942. On November 17, 1949, an earthquake movement at about the 1,600 ft level resulted in casing offsets so severe as to cause abandonment of many wells. Certain areas of the pool were completely redeveloped. The production performance of these recompletions was so markedly superior even to that of the original performance of wells drilled seven t eight years earlier in the life of the pool that five-spotting and replacement drilling were undertaken over the entire reservoir. Completion practices used in redrilling and in the original wells are contrasted. Reservoir characteristics and the history of reservoir performance are discussed. This history is dominated by the effects of the recompletions and additional development which took place after the earthquake.

339-G
Study of Undersaturation During Repressuring and Supersaturation During Flow of Oil to Wells

R. V. Higgins, U. S. Bureau of Mines

This paper concerns the magnitude of the amount of supersaturation that occurs in an underground reservoir during the flow of oil and gas to wells and to the amount of undersaturation that occurs during repressuring of an oil reservoir where some effective permeability to gas exists. The study is based on earlier laboratory findings of other investigators on the rate of diffusion of gas in oil as a function of the depth of oil. Utilizing those relationships and the principles of reservoir mechanics, a quantitative estimate of undersaturation and supersaturation was calculated. The results showed that the diffusion of the gas is rapid enough so that for all practical purposes no supersaturation exists during the flow of oil to wells and no undersaturation obtains during repressuring of reservoir sands having some effective permeability to gas.

340-G
Solution of the Equations of Unsteady-State Two-Phase Flow in Oil Reservoirs

W. J. West and W. W. Garvin, California Research Corp., and J. W. Sheldon, International Business Machines Corp.

One of the most important problems of reservoir mechanics is the prediction of the behavior of a gas and oil producing reservoir for a variety of production programs. In the absence of a knowledge of the behavior of even idealized systems, it has been difficult, if not impossible, to determine which production program would yield maximum economic recovery. The problem in idealized form was formulated mathematically many years ago, but a solution of the equations had never been obtained because of their extreme complexity. The solution of the problem became possible, however, with the advent of modern computing machines. This paper describes a digital method of solving the problem and discusses some of the results which have been obtained to date. All derivatives were replaced by finite differences to bring the equations into a form suitable for digital calculations. A number of finite difference formulations were investigated and one form was found which resulted in stable, convergent solutions. This form was used to obtain solutions for both radial and linear systems producing by solution gas drive.

EJC Changes Approved Allowing New Members

Enlargement of Engineers Joint Council to include other engineering societies makes certain changes in its constitution advisable. At the June 17 meeting of the AIME Board, these changes, giving the qualifications under which a national engineering society might become a constituent body, were approved. They would provide: (1) The corporate or voting membership shall be confined to individual members (not corporations or company members). (2) A majority of individual members shall be either graduates of engineering colleges of recognized standing or shall be licensed or registered by a State Board of Registration for Professional Engineers. (3) The society shall have a total membership of at least 5,000 individual members of which the majority must meet the above requirements. (4) Request for admission shall receive the affirmative vote of not less than two-thirds of the constituent societies of the Council.

At present, EJC comprises the ASCE, AIME, ASME, AIEE, AIChE, Society of Naval Architects and Marine Engineers, American Society for Engineering Education, and American Water Works Association. ★ ★ ★

New Local Section Plan To Be Voted on By Board

At the meeting of the Inter-Branch Council in Los Angeles, Feb. 15, 1953, a resolution was passed recommending that the AIME Board of Directors change the Bylaws so that more than one Local Section in a given geographical area be permitted. The reasoning was that in certain Local Section areas Division or Branch interests could be served better if a Local Section devoted to their specific interests were organized. Heretofore, Local Sections whose membership had diverse professional interests either had little to offer members in their particular professional field, or operated through a loose sponsorship of small groups or sub-Sections. In some Sections such organization was satisfactory, in some others not.

The Executive and Finance Committees considered the resolution at their meeting on April 15, and the Board discussed the matter further at the meeting of June 17. No particular objection was offered to the idea of overlaying Local Sections provided the Council of Section Delegates is not unduly enlarged thereby and that the cost of supporting Local Section activities does not increase. In any case, the proposed change in the Bylaws would be permissive only, as to establishing overlaying Local Sections, and no Section could be established or continue in existence without approval of the Board. This would give the Board authority to take action on canceling a Local Section if cause therefor developed. It was generally agreed that Section Delegates should represent areas rather than Local Sections if the plan were in effect.

The Board voted to propose to delete the following words from Article XI, Section 3, of the Bylaws (page xlvii, 1st column, of the 1952-53 Directory): "Only one Section shall be authorized in any one locality or district and . . ."

The Board will vote on this change in the Bylaws at its meeting in Seattle on Sept. 22. If the change is authorized at that time, members will be advised of the procedure to be followed in setting up new Local Sections in areas already covered. ★ ★ ★

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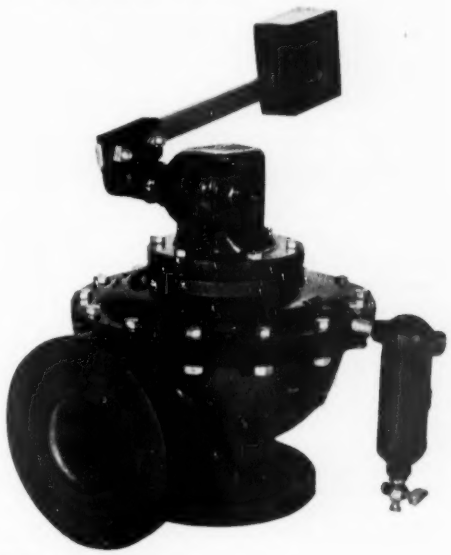

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Local Section Allotments To Total Some $10,000

Reduced appropriations to Local Sections for 1953 were not questioned by a majority of the Sections but 15 or so expressed opposition to the action for one reason or another. The Board considered these objections at its meeting on June 17, and voted to increase the current distribution to $10,000.

The Committee was to make a further study of the matter in July and to recommend increasing the allotments to some of the Local Sections whose treasuries appear to be most in need of support. It is expected that the Council of Section Delegates will study the matter carefully, discuss it at its meeting next February, and make a recommendation to the Board as to the degree of financial support to be accorded Local Sections in the future. ★

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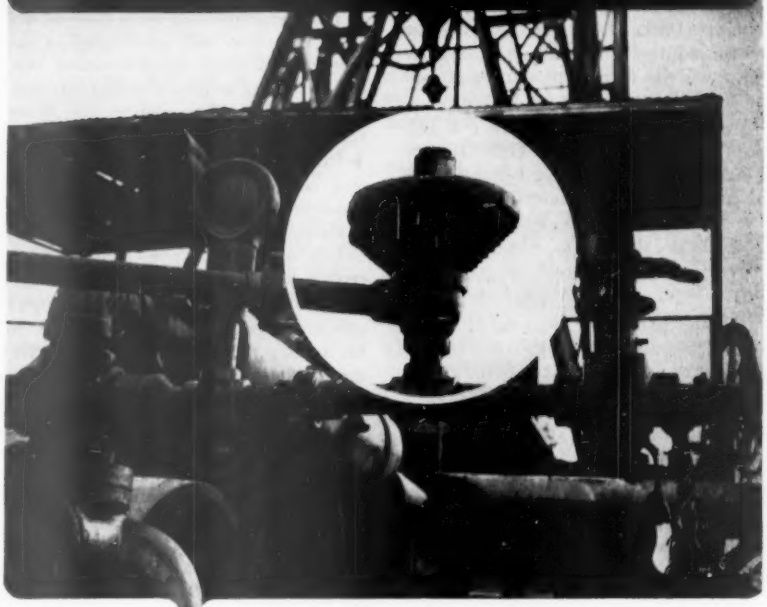

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Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to personnel notice P-5 and positions coded Y8555, Y8914-D8656, Y8035, Y7547 and C1091 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦ Mud engineer, 26, single, with two years' mud engineering experience for mud company. Four years of mud research relating to drilling and reservoir problems for major oil company. Desires position with large independent or major oil company, domestic or foreign. Code 198.

♦ Petroleum geologist, 30, 3 years' varied experience with major wishes to relocate in Rocky Mountain area with aggressive independent. Presently employed. Code 199.

♦ Petroleum Engineer with major oil company desires change and connection with independent. Seven and one-half years' experience in drilling, production of both oil and gas and work over operations in Corpus Christi area. Willing to, and capable of, assuming full responsibility of operations. Code 200.

♦ Qualified exploration manager, experienced in U. S. and foreign leasing, geological reconnaissance, and petroleum exploitation engineering, desires position with strong independent, on salary, carried interest, or similar basis. Optimistic attitude, with some fields discovered in areas favorably recommended, plus some immediate favorable areas, makes this an opportunity for an aggressive operator to increase his production quickly. Location immaterial. Code 201.

♦ Petroleum Engineer, Oklahoma Univ. graduate. Five years' experience refinery and chemical plant layout and design; nine years' current experience with sales force of national engineering concern. Desires more active sales responsibility. Strong self and administrative ability. P-5.

POSITIONS

♦ Excellent opportunity for man with experience in secondary oil recovery by water flooding who has formal training in microbiology to do sales and service work with firm well established in the field of industrial microorganism control. Training period, salary plus commission. All replies confidential. Write fully. Code 548.

♦ Professor to teach petroleum production courses, and direct and conduct fundamental research in the field of reservoir mechanics. PhD. desirable. Salary open. College located in south central United States. Code 549.

♦ Petroleum engineer, young man with one or two years' field experience, to fill teaching position in western mining college. Must have M.S. in petroleum engineering. Code 550.

♦ Reservoir engineer — A large unit operation desires to hire an engineer with a minimum of two years' experience as reservoir engineer plus some field petroleum engineering experience. Applicants should state education and experience in letter of inquiry. All inquiries will be acknowledged. Code 551.

♦ Expanding chemical and fracturing service firm requires petroleum engineers under 30 for development and sales work. Limited experience acceptable. Firm is one of the oldest in the business, operating in Texas, Oklahoma, Louisana, New Mexico, and Kansas. Code. 552.

♦ Chief petroleum engineer to organize the work and direct the petroleum engineering group in a Far East operation; should have 7 to 10 years' petroleum engineering experience in drilling and production, and be able to supervise 8 to 10 pertoleum engineers. Salary is open and includes living expenses and foreign service bonus. Code 553.

♦ Sales Engineer, 26-30, with engineering degree and equipment experience, for sales and service of liquified petroleum gas facilities. Traveling in East. Salary, $5100 a year. Headquarters, New York, N. Y. Y8555.

♦ Recent graduates for large refiner of petroleum and chemical products. (a) Chemists and chemical engineers for operation analysis, process design or economics. (b) Mechanical, electrical and chemical for project engineering, field engineering or equipment inspection. Salaries open. Location, South. Y8914-D8656.

♦ Technical sales engineer for petroleum products sales in Bombay, India. Should have eight to ten years' experience in industrial sales, preferably chemical or petroleum. Salary open. Twenty-five per cent premium for overseas service plus cost of living and housing allowances. Y8035.

♦ Professor, preferably with Ph.D. degree, to take charge of courses in the field of petroleum production engineering, and also do some research work along the line of reservoir engineering. Attractive salary. Location, Southwest. Y7547.

♦ Sales engineering trainee, 25-29, to sell complete lubricating program to industrials covering full line of petroleum products. Will deal with top management for most part. Must have been an honor student and have definite sales aptitude. Knowledge of industrial machinery desirable. Salary, $400-$450 month. Employer will negotiate fee. Location, Chicago. C1091.

♦ Continental Oil Co. has several openings for petroleum engineers in the Rocky Mountain region, minimum of three years' experience required. Also opening for mechanical engineer with oil field experience. Applicants contact C. C. Frye, regional petroleum engineer, 1755 Glenarm Place, Denver, Colo.

New Fund Set Up By 1934 AIME President

Terms of the will of the late Howard N. Eavenson, President of the Institute in 1934, were recently made known to AIME Directors. The money will be available as a trust fund after the death of Mrs. Eavenson, and the income is to be used for the following purposes: (1) To defray the cost of publishing papers of interest to members of the Coal Division. (2) To establish the Howard N. Eavenson Award to amount to at least $500, with an embossed certificate, to be given from time to time to a person who has contributed the most to the advancement of the coal industry. (3) For other purposes of the Coal Division if the annual income is not used as specified in (1) or (2).

This large gift will bring the total general endowed funds of the AIME to approximately $960,000. The principal other Funds are the James Douglas Library Fund, $110,000; Rocky Mountain Club Fund, $114,000; Seeley W. Mudd Fund, $106,000; Gorge D. Barron Fund, $133,000; and Henry L. Doherty Fund, $98,000. ★ ★ ★

Proposed for Membership, Petroleum Branch

Total AIME membership on May 31, 1953, was 18,822; in addition 1,227 Student Associates were enrolled.

PETROLEUM BRANCH ADMISSIONS COMMITTEE

J. H. Sullivan, Chairman; Thomas S. Bacon, Vice-Chairman; A. E. Caraway, Frank C. Kelton, Thomas E. Morton, and F. C. Prutzman.

INSTITUTE ADMISSIONS COMMITTEE

O. B. J. Fraser, Chairman; Philip D. Wilson, Vice-Chairman; F. A. Ayer, A. C. Brinker, R. H. Dickson, Max Gensamer, Ivan A. Given, Fred W. Hanson, T. D. Jones, G. W. Lutjen, E. A. Prentis, Sidney Rolle J. T. Sherman, F. T. Sisco, and R. L. Ziegfeld.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

CALIFORNIA

Bakersfield — Holden, Cyril Dwain (J).
Laguna Beach — Shaffer, John Charles (M).
Los Angeles — Taylor, Clifford James (M).
Sierra Madre — Austin, Marion D. (M).

GEORGIA

Atlanta — Sargent, William Moffet, Jr. (J).

LOUISIANA

Lafayette — Trash, Purvis James (R, C/S, S-J).

New Orleans — Brown, Dexter Hanson (J); Reynolds, Gene Richard (J).

MISSISSIPPI

Laurel — Lilly, Wilbur Roy (C/S, S-J).

MONTANA

Billings — Cowan, John Gilmore (M).

NORTH DAKOTA

Tioga — Black, William A. (J).

OKLAHOMA

Tulsa — Strother, G. Dudley (M); Walker, Richard Ebersole (J).

TEXAS

Dallas — Bowen, William Jackson (M); Oliver, Fred Lamar (J); Stade, Paul Wilson, Jr. (R, J).

Fairbanks — Boggess, Billy Moore (J).

Houston — Choate, Bobby Lee (J); Coleman, James Truett (C/S, S-J); Elsbury, Joe W., Jr., (J); Ford, Francis Dee (J); Maxwell, Curtis Fred (R, M); Ribe, Kenneth Harris (J); von Rosenberg, Dale Ursini (J).

Midland — Atteberry, Donald Ray (R, C/S, S-J); McDonnold, Stout Scott (J); Plumb, Leslie B., Jr. (J).

Odessa — Attix, Edwin W. (J).

PERU

Lima — White, Richard McIntyre, Jr. (R, C/S, S-J).

SAUDI ARABIA

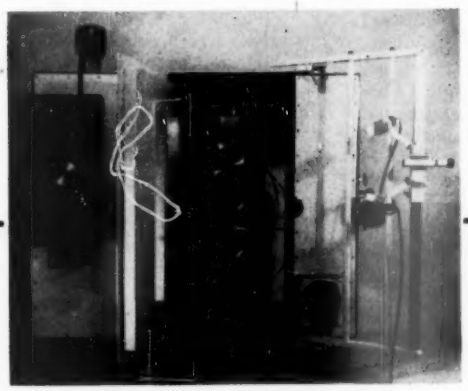
Dhahran — Hilton, Fred Arthur (C/S, A-M).

Socony-Vacuum Extends Senior Scholarship

Jack I. Laudermilk advises that the Socony-Vacuum Oil Co. will again support financially the scholarship offered to senior petroleum engineering students for the first time last year. The colleges with petroleum engineering curricula have been notified. High scholastic achievement and intention to enter the petroleum industry immediately on graduation are the principal qualifications for the $750 award. Administration of the scholarship is in the hands of a committee consisting of Allison Butts, chairman, Paul R. Turnbull and D. V. Carter. ★ ★ ★

AIME Bolsters UPADI

AIME Directors have voted the sum of $603 from the Eilers Fund as a contribution to Engineers Joint Council which will be used to finance UPADI (Union Panamericana de Asociaciones de Ingenieros) activities on a restricted scale during the current year. The contribution, totaling some $4,500, is in the form of a loan to the UPADI Fund. When financing is completed it is expected that the loan will be repaid. ★



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Personals

HAROLD B. RENFRO has announced the establishment of his office in Dallas as a petroleum consultant. The move was effective June 1, 1953, and his office will be located at 4225 Greenbrier.

Renfro

He will engage in appraisals, valuations and unitization work.

A native of Texas, Renfro was graduated from the University of Tulsa with a B.S. degree in petroleum engineering in 1939. He then attended the University of Wisconsin from 1939 to 1942, receiving both the M.S. and Ph.D. degrees in Geology there.

After serving in the U. S. Navy from 1942 to 1946, Renfro joined the faculty of the University of Tulsa as Professor of Geology. In June, 1948, he affiliated with Stoddard Oil Co. of Dallas as engineer and geologist, and continued there until establishing his own office.

+

J. M. WANENMACHER of Keplinger and Wanenmacher, consulting petroleum engineers, Tulsa, Okla., has gone to Colombia, South America, to visit the De Mares Concession of Empresa Colombiana de Petroleos, located in the Magdalena Valley. He will be gone approximately one month.

+

The announcement of two promotions was made by the Lane Wells Co. recently. JOHN J. NEALE, formerly Gulf Coast Division manager, has been made assistant to the president, moving from Houston to Los Angeles. Neale began with Lane Wells in 1936 as a loader.

JOSEPH H. HENDERSON, formerly assistant Gulf Coast Division manager, will take his place as manager. He also joined Lane-Wells in 1936. Both are A&M graduates.

+

MAC D. OLIVER has been elected a director and vice president in charge of engineering of San Juan Oil Co., Robert J. Bradley, president, has announced. Oliver, who has been with the company for over two years, is a graduate of Texas A&M. In addition to being in charge of all engineering, he is the managing partner for Bradley, Oliver and Associates, petroleum consulting firm operated in connection with San Juan Oil Co.

+

WILLIAM L. ROBBINS has been promoted by the Carter Oil Co. from junior engineer, in Great Bend, Kansas, to petroleum engineer in secondary recovery at Tulsa, Okla.

+

JACK A. CRICHTON has been named president, Oil and Gas Property Management, Inc., and vice president of Empire Trust Co., with offices in the Fidelity Union Life Bldg., Dallas.

Crichton is a past vice president and director of DeGolyer and MacNaughton, Dallas. He received a B.S. degree at Texas A&M, a M.S. from Mass. Institute of Technology, and a Professional degree from Texas A&M.

+

S. K. MOREDOCK, on completion of 13 months training in Dallas, Tex., and Washington, D. C., has been assigned to the Engineering and Valuation Section of the Bureau of Internal Revenue, Oklahoma City, Okla.

+

B. H. MURPHY, formerly located in Newport Beach, Calif., has taken a position with Producers, Inc., as production engineer in Ft. Worth, Texas.

+

CALVIN C. STEINBERGER, Bellaire, Tex., formerly in Gainesville, has formed a partnership with his father as a geologist and engineer. The firm will be called Steinberger & Son.

+

JACK E. HAUGHN, has become associated with the firm of Kirkpatrick and McGuire, consulting petroleum engineers, of Shreveport, La. A graduate of the University of Texas, Haughn was employed by the Orchem Corp. while a student. Since graduation, he has worked with Dowell Incorporated.

Haughn will assist with making special reservoir studies and in field work for primary and secondary recovery operations.

NICK VAN WINGEN, petroleum engineer and vice president of Petroleum Technologist, Inc., Montebello, Calif., has announced his resignation from that position to engage in private practice as a consultant, with offices at 903 Fair Oaks Ave., South Pasadena, Calif. He will retain his place on the Petroleum Technologists board of directors.

He is a graduate of California Institue of Technology of the University of Calif. He was formerly chief evaluation engineer for Richfield Oil Corp., and has had wide experience in phases of oilwell drilling and production over the past 20 years.

He is presently in Turkey, where he will make an engineering evaluation of its two oil fields for the Turkish government, and will return sometime in September.

+

ROY F. CARLSON has joined the staff of the Division of Production of the American Petroleum Institute in Dallas as assistant to the director, effective August 1. He will be in charge of the Division's drilling and production practice programs, and district activities.

Carlson has been a member of the editorial staff of the *Oil & Gas Journal* since 1948, and was recently West Texas editor. He is a native of Colorado and attended the Colorado School of Mines, obtaining his degree from Tufts College.

Carlson

Adair

WILLIAM B. ADAIR has recently accepted a position as sales engineer with Macco Oil Tool Co., in Houston, Tex., selling and servicing gas lift equipment in the Houston and Gulf Coast area. He was formerly associated with Associated Engineers, Inc., in Houston, as a petroleum engineer.

Adair graduated with a B.S. in petroleum engineering, attending both Texas A&M and the University of Texas.

Schedule of Local Section Meetings

DALLAS SECTION

Meeting City: Dallas, Tex.

CHAIRMAN	SECRETARY
E. R. Brownscombe	T. E. Morton
Atlantic Ref. Co.	Halliburton
Dallas, Tex.	Dallas, Tex.
PR-6484	RI-3841

Meets third Monday each month

DELTA SECTION

Meeting City: New Orleans, La.

ACTG. CHRM.	SECRETARY
A. L. Vitter	Byron L. Francis
California Co.	The Texas Co.
New Orleans, La.	New Orleans, La.
	CA-8592

Meets second Tuesday each month

EAST TEXAS SECTION

Meeting Place: Gregg County Airport

CHAIRMAN	SECRETARY
H. L. Long	H. D. Miller
Independent Oil Op.	Amerada Pet. Corp.
Kilgore, Tex.	Longview, Tex.
Phone 4416	Phone 1878

Meets second Tuesday each month

FORT WORTH SECTION

Meeting City: Fort Worth, Tex.

CHAIRMAN	SECRETARY
H. J. Gruy	T. M. Curtis
Consultant	Stanolind Oil & Gas
Fort Worth, Tex.	Fort Worth, Tex.
FO-6157	FO-5661

Meets third Tuesday each month

GULF COAST SECTION

Meeting City: Houston, Tex.

CHAIRMAN	SECRETARY
Kenneth B. Ford	Pete Cawthon, Jr.
J. R. Butler & Co.	City National Bank
Houston, Tex.	Houston, Tex.
AT-9455	FA-2131

Meets third Tuesday each month

ILLINOIS BASIN CHAPTER

Meeting City: Salem, Ill.

CHAIRMAN	SECRETARY
Jerry Vaughan	Harry Bridges
Sun Oil Co.	Shell Oil Co.
Evansville, Ind.	Centralia, Ill.
Phone 3-4291	Phone 711

Meets first Thursday each month
(No meetings during July and August)

KANSAS SECTION

Meeting Cities: Wichita and Great Bend, Kans.

CHAIRMAN	SECRETARY
J. R. Puckett	John T. Gary
Magnolia Pet. Co.	Continental Oil Co.
Wichita, Kans.	Wichita, Kans.
4-1301	7-8347

Meets second Wednesday in Wichita, fourth Thursday in Great Bend
(No meetings during June, July and August)

LOU-ARK SECTION

Meeting City, Shreveport, La.

CHAIRMAN	SECRETARY
A. H. Crawford	L. R. Lacy
Crawford Drilling Co.	Phillips Pet. Co.
Shreveport, La.	Shreveport, La.
4-4441	2-3124

Meets tentatively first Monday each month

MID-CONTINENT SECTION

Meeting City: Tulsa, Okla.

CHAIRMAN	SECRETARY
G. C. MacDonald	F. H. Callaway
Gulf Oil Corp.	Stanolind Oil & Gas Co.
Tulsa, Okla.	Tulsa, Okla.

Meets second Monday each month
(Study Group meets fourth Tuesday each month)
(Luncheon meetings each Thursday, Mayo Hotel)

NORTH TEXAS SECTION

Meeting City: Wichita Falls, Tex.

CHAIRMAN	SECRETARY
Rollie P. Dobyns	John H. Bolstad
U. S. Bureau of Mines	Continental Oil Co.
Wichita Falls, Tex.	Wichita Falls, Tex.

Meets second Monday each month

MISSISSIPPI SUB-SECTION

(of Delta Section)

Meeting Cities: Laurel, Jackson and Natchez, Miss.

CHAIRMAN	SECRETARY
John A. Rodgers	Paul Tsimortos
Gulf Refining Co.	Gulf Refining Co.
Lumberton, Miss.	Lumberton, Miss.
Phone 4501	Phone 4653

OKLAHOMA CITY SECTION

Meeting City: Oklahoma City, Okla.

CHAIRMAN	SECRETARY
L. F. Elkins	C. R. Miller
Sohio Petroleum Co.	Schlumberger
Oklahoma City	Oklahoma City
RE-90511	RE-91487

Meets third Thursday each month

PACIFIC PETROLEUM CHAPTER

Meeting City: Los Angeles, Calif.

CHAIRMAN	SECRETARY
F. L. Wadsworth	C. K. Ferguson
General Pet. Corp.	California Research
Los Angeles, Calif.	La Habra, Calif.
MA6-5711	OX7-1721

PERMIAN BASIN SECTION

Meeting Cities: Midland and Odessa

CHAIRMAN	SECRETARY
J. C. Blackwood	Maurice Lewis, Jr.
Amerada Pet. Corp.	British-American Oil
Midland, Tex.	Midland, Tex.
Phone 4-5533	Phone 4-8021

Meets third Monday each month

SAN JOAQUIN VALLEY GROUP

(of Pacific Petroleum Chapter)

Meeting City: Bakersfield, Calif.

CHAIRMAN	SECRETARY
R. P. Mangold	C. A. Davis
D. K. Partnerships	Richfield Oil Corp.
Bakersfield, Calif.	Bakersfield, Calif.
Bakersfield 32561	Maricopa 92631

Meets first Tuesday alternate months
(Feb., April, June, Aug., Oct., Dec.)

SOUTH PLAINS SECTION

Meeting City, Lubbock, Tex.

CHAIRMAN	SECRETARY
J. W. Brown	J. B. Livingston
Stanolind Oil & Gas	Haliburton Oil Well
Brownfield, Tex.	Cem. Co.
Phone 2166	Lubbock, Tex.
	Phone 5-5725

Meets third Thursday each month

SOUTHWEST TEXAS SECTION

Meeting City: Corpus Christi, Tex.

CHAIRMAN	SECRETARY
Ivan Tucker	Chester L. Wheless
Atlantic Ref. Co.	La Gloria Corp.
Corpus Christi, Tex.	Corpus Christi ,Tex
Phone 3-9372	Phone 3-8553

Meets third Wednesday each month
(No meetings July, August and December)

WEST CENTRAL TEXAS SECTION

Meeting City: Abilene, Tex.

CHAIRMAN	SECRETARY
J. L. Coulson	J. E. Russell
Warren Pet. Corp.	Reddin Oper. Comm.
Abilene, Tex.	Abilene, Tex.
Phone 4-8113	Phone 2-4031

Meets third Wednesday each month

WYOMING SECTION

Meeting City: Casper, Wyo.

CHAIRMAN	SECRETARY
R. D. Ferguson	W. R. Kahla
U. S. Geological Surv.	Ohio Oil Co.
Casper, Wyo.	Casper, Wyo.
Phone 3-4561	Phone 3-5721

Meets in alternate months
(No specific dates set)

AIME MEETING CALENDAR

Petroleum Branch Fall Meeting — Oct. 18-21, 1953, Baker and Adolphus Hotels, Dallas, Tex.; Oct. 17-20, 1954, San Antonio, Tex.

Pacific Petroleum Chapter Fall Meeting — Oct. 1-2, 1953, Ambassador Hotel, Los Angeles, Calif.

AIME Fall Meeting — Oct. 29-31, 1953, El Paso, Tex.

AIME Annual Meeting — Feb. 14-18, 1954, Statler Hotel, New York, N. Y.

Advertisers' Index

American Iron & Machine Works . . . . Sec. 1 — 52
Lowe Runkle Co., Oklahoma City, Okla.

Associated Equipment, Inc. . . . . Sec. 1 — 44
Clausel Industrial Adv., Houston, Tex.

Baash-Ross Tool Co. . . . . Sec. 1 — 73
Dozier-Eastman Co., Los Angeles, Cal.

Baker Oil Tools, Inc. . . . . Sec. 1 — 6, 7
Theo. M. Martin Co., Los Angeles, Cal.

Baroid Sales Division . . . . . Sec. 1 — 29, 30
Brennan Advertising, Houston, Tex.

Barret, Wm. M., Inc. . . . . *
Bozell & Jacobs, Inc., Shreveport, La.

B & W, Inc. . . . . Sec. 1 — 25
Brennan Advertising ,Houston, Tex.

Byron Jackson Co. . . . . *
Ruthrauff & Ryan, Los Angeles, Cal.

Camco, Inc. . . . . Sec. 1 — 70
Rives, Dyke & Co., Houston, Tex.

Clark Bros. Co., Inc. . . . . *
Harold Warner Co., Buffalo, N. Y.

Cooper-Bessemer Corp. . . . . Sec. 1 — 60
Griswold-Eshleman Co., Cleveland, Ohio

Core Laboratories, Inc. . . . . Sec. 1 — 4
Duvall Williams, Dallas, Tex.

Dowell Incorporated . . . . . Sec. 1 — 8
MacManus, John & Adams, Inc., Detroit, Mich.

Dresser Industries, Inc. . . . . Sec. 1 — 36, 37
Laughlin, Wilson, Baxter & Persons, Dallas, Tex.

Eastman Oil Well Survey Co. . . . . *
Ted Workman Advertising, Dallas, Tex.

Geolograph Co. . . . . Sec. 2 — 8
Lowe Runkle Co., Oklahoma City, Okla.

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Casper, Wyo.—Glendive, Mont.—Sterling, Colo.
Calgary and Edmonton, Alberta, Canada
Regina, Saskatchewan, Canada

Geological Well Service Co. . . . . Sec. 2 — 5
Matlock-Wilson Advertising, Dallas, Tex.

Geophysical Research Corp. . . . . Sec. 1 — 58
Gibbons Advertising, Tulsa, Okla.

Halliburton Oil Well Cementing Co. . . Sec. 1 — 1, 84
Hill & Christopher, Los Angeles, Cal.

Harbison-Fisher Mfg. Co. . . . . *
Dan Goodrich, Dallas, Tex.

Hudson Engineering Corp. . . . . Sec. 1 — 66
Brennan Advertising, Houston, Tex.

Hughes Tool Co. . . . . Third Cover
Foote, Cone & Belding, Houston, Tex.

Hycalog Co. . . . . Sec. 1 — 10
Glenn Mason Advertising, Shreveport, La.

Johnston Testers, Inc. . . . . Sec. 1 — 55
Wallace Davis & Co., Houston, Tex.

Keystone Development Corp. . . . . Sec. 1 — 46
Brennan Advertising, Houston, Tex.

Kobe, Inc. . . . . *
The McCarty Co., Los Angeles, Cal.

Kimray, Inc. . . . . Sec. 2 — 1
Brandenburg Advertising, Tulsa, Okla.

Kinzbach Tool Co., Inc. . . . . Sec. 2 — 3
Wallace Davis & Co., Houston, Tex.

Lane-Wells Co. . . . . Fourth Cover
Darwin H. Clark Co., Los Angeles, Cal.

Lufkin Foundry & Machine Co. . . . . Sec. 1 — 50
A. E. Cudlipp, Lufkin, Tex.

Magnet Cove Barium Corp. . . . . Sec. 1 — 36, 37
Rives, Dyke & Co., Houston, Tex.

McCullough Tool Co. . . . . Sec. 1 — 62
R. P. Casterline, Los Angeles, Cal.

Mission Manufacturing Co. . . . . *
Rives, Dyke & Co., Houston, Tex.

Moore, Lee C., Corp. . . . . Sec. 1 — 20
Watts, Payne Advertising, Tulsa, Okla.

Oil Base, Inc. . . . . *
Dozier-Eastman & Co., Los Angeles, Cal.

Oil Center Tool Co. . . . . Sec. 1 — 49
Rives, Dyke & Co., Houston, Tex.

Otis Pressure Control, Inc. . . . . Sec. 1 — 42
Dan Goodrich, Dallas, Tex.

Pelton Water Wheel Co. . . . . *
Edward A. Stratman, Huntington Park, Cal.

Petty Geophysical Engineering Co. . . . . Sec. 1 — 76
Wallace Davis & Co., Houston, Tex.

Professional Services . . . . . Sec. 2 — 2, 3

Rector Well Equipment Co., Inc. . . . . Sec. 1 — 38
Wallace Davis & Co., Houston, Tex.

Reed Roller Bit Co. . . . . Sec. 1 — 2
Brennan Advertising, Houston, Tex.

Ruska Instrument Corp. . . . . Sec. 2 — 5
Brennan Advertising, Houston, Tex.

Schlumberger Well Surveying Co. . . . Second Cover
Rives, Dyke & Co., Houston, Tex.

Second National Bank of Houston . . . . . *
Gano, Bachrodt, Edwards, Inc., Houston, Tex.

Security Engineering Division . . . . . Sec. 1 — 35
The McCarty Co., Los Angeles, Cal.

Seismic Exploration, Inc. . . . . Sec. 1 — 79
Rives, Dyke & Co., Houston, Tex.

Shaffer Tool Works . . . . . Sec. 1 — 22
Dozier-Eastman Co., Los Angeles, Cal.

Sperry-Sun Well Surveying Co. . . . . Sec. 1 — 32
Wallace Davis & Co., Houston, Tex.

United Geophysical Co., Inc. . . . . *
Dozier-Eastman Co., Los Angeles, Cal.

Welex Jet Services, Inc. . . . . Sec. 1 — 57
Evans & Assoc., Fort Worth, Tex.

Western Co., The . . . . . Sec. 1 — 26
Ted Workman Advertising, Dallas, Tex.

Western Geophysical Co. . . . . *
L. J. Swain Advertising, Whittier, Cal.

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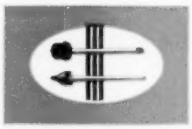
Hughes OSC Series bits (OSC, OSC-1, OSC-3) are used in oil fields throughout the world.

"Shore purty...but how does she shoot?"

No matter how pretty the package, everything in the end rests on the question — how well does it *work!* The guns used in Lane-Wells Gun Perforating aren't particularly beautiful, but 190,000 perforating jobs in all the oil fields of this country prove that they do the job they were built for — and do it *right,* the first time! Because, operators' records show an efficiency of 97% — a perforating record that has no equal. Ask your Lane-Wells man.

Tomorrow's Tools Today!®



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